A GRADUATED COURSE OF NATURAL SCIENCE

PART I

LOEWY

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NATURAL SCIENCE

EXPERIMENTAL AND THEORETICAL

FOR

SCHOOLS AND COLLEGES

PART I.—FIRST YEAR'S COURSE

FOR ELEMENTARY SCHOOLS AND THE
JUNIOR CLASSES OF COLLEGES AND TECHNICAL SCHOOLS

BY

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PREFACE

In the present work I have made an attempt to bring the instruction in Natural Science given in our better schools into harmony with educational principles and methods, and to place those fundamental facts of Physics and Chemistry, which should not only be the common property of all educated men, but form the recognised foundation for every scientific pursuit, upon a purely experimental basis.

In accordance with my first aim I have arranged the principal subjects, which are usually embraced by a school course in Physics and Chemistry, in a progressive manner; so that the pupil may be able to proceed gradually from that which is known, simple, and easy, to that which is unknown, complex, and difficult; from that which is near and within a young learner's perception to what is more recondite. With regard to my other aim, I have strictly carried out the plan to convey no instruction but that which is conveyed through experiments and the immediate consequences of the phenomena observed, as deduced by a chain of simple reasoning. The pupil is thus early trained in the very methods which are employed by the highest inquirers after scientific truth. Though the experiments themselves are invariably so selected as to be of the most

simple kind, yet they present many opportunities for gradually training hands and senses to useful manipulation and exact observation.

More than twenty years' experience in teaching Physics and Chemistry to large classes, both in the lecture-room and in the laboratory, has taught me as regards Science-teaching what can be done in schools and what cannot be done; and in the following volumes I have given to my fellow-workers as the result of my experience that only which can really be done thoroughly and honestly. In asking other teachers to examine my arrangement of facts and principles, and to make themselves acquainted with my methods, I wish to guard myself against the possible assumption that the present work is intended to replace text-books or laboratory guides in either Physics or Chemistry. An examination of its contents will prove that it chiefly aims at laying a sure foundation for the proper and most advantageous use of systematic treatises.

In judging of my attempt and the manner in which my intentions have been carried out, I hope it will not be forgotten that the excellent methods applied in other branches of school instruction with such admirable results have been worked out by the united efforts of many generations of teachers, and it will be a long time before the Science-teaching in schools will be placed on similar foundations. I for my part shall rest well satisfied if I have succeeded in this work in giving an impulse to others, who will carry the work onwards into the future.

The present volume is a first year's course of work for beginners. It is intended to give a thorough insight into some of the most common phenomena of everyday life,

the nature of which should be well known to every boy and girl who leaves school. The thread which connects the material phenomena presented in this volume is "the mutual action of matter," and I have taken care to introduce only those kinds of interactions of matter which experience has proved to be really intelligible to young beginners.

A few remarks on the way in which I have used and tested the contents of this volume may be useful. Each of the twenty-five chapters gives work, on an average, for a fortnight, assuming that not less than two hours weekly are given to Science in a school. The experiments—which present so little manual difficulty that every able schoolmaster, even if he had no scientific training, could perform them with ease—should be done first by the teacher, and if possible by all pupils afterwards. A glance at Appendix B will show that the whole of the materials, etc., required for the experiments could be obtained even for large classes at a very small expense. I find that two or three pupils can work together quite well, by standing before a board of about $2\frac{1}{2}$ or 3 feet length and 18 inches width, which is screwed when required to the ordinary school desk, and can easily be removed. An ordinary schoolroom will allow thirty or forty pupils to work conveniently. The possibility of carrying out such an arrangement will naturally depend on the authorities of the school. Only in a very few of the experiments such an arrangement is indispensable, in most others it is sufficient that the experiment be made by the teacher, provided that each pupil has an opportunity of clearly seeing what is going on. Each experiment should be fully discussed before the next

is entered upon, and the whole work of every lesson should be read over by each pupil in this book, and written out in a separate book in his own words as far as possible, as repetition. The questions at the end of each chapter form an examination upon the whole; they should be answered by each pupil in class without looking back at the text, and these answers should be corrected by the teacher; or the questions may be used for an oral repetition, if the time of the teacher will not permit him to revise written answers thoroughly. Each chapter will be found to give many opportunities for widening the range of the pupil's knowledge by conversational information and instruction.

I have to express my great obligation to an esteemed old pupil, L. R. Wilberforce, M.A., of Trinity College and the Cavendish Laboratory, Cambridge, for having devoted much time and considerable care to the revision of the text, and for his many valuable suggestions and improvements, which have been greatly to the advantage of the work.

February 1889.

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CHAPTER I

WE ARE SURROUNDED BY AIR

THE Earth which we inhabit is said to be surrounded by air. How can we prove this ? The answer is that though air cannot be seen it can be *felt.*

Experiment 1.—Hold one corner of a sheet of stout paper between the thumb and forefinger of your right hand, move the flat side several times to and fro from right to left, and hold your left hand so that the edge of the moving paper passes by it.

You feel the air as it moves against your left hand like a gentle wind. Your hand in moving the paper pushes aside the air in front of the paper, and air in motion can be felt. You feel the air whilst running, or riding in a carriage which is going fast; it is then your own body, or the carriage, which is doing the same thing that the sheet of paper does in your experiment.

All things which we can either *see*, or *hear*, or *feel*, or *smell*, or *taste*, are thereby proved to exist. We have just proved that air exists, for we can feel it. But we can also hear it. The howling of the wind is an example of this. A whistle gives out no sound of itself, but take it and blow air through it : you will hear the air immediately. Notice in this case also that we cannot hear the air unless it is in motion.

The existence of air is thus proved by our being able to feel and to hear it; and wherever human beings have gone to on the surface of the earth, the existence of air has been proved in the same way. From this it follows that our earth is surrounded on all sides by air. The whole of this air has been called the *atmosphere* (from the Greek words *atmos*, air; and *sphaira*, a globe).

Experiment 2.—Hold the paper as before between the thumb and forefinger, but now instead of moving its flat side move its edge from right to left, again holding your left hand near the moving edge.

You will scarcely feel anything now, for the sharp edge sets a much smaller quantity of air in motion than the broad flat side of the paper. You will further observe another point in which this experiment differs from the last. In moving the broad flat side of the paper backwards and forwards you feel that you have to put forth more effort than in moving the narrow edge; you feel that the air resists the motion of the paper much more when the side is moved and more air is pushed aside than when the edge is moved and less air is set in motion. In other words, the more air you set in motion the more *work* you must do. When you move your paper the air in front presses against it more than that behind, and you must do work to overcome this excess of pressure if you wish to move the paper; the larger the sheet of paper the more air presses against it in front and behind, and the more work is required on your part for moving the paper.

If air is all round us, it must fill every vessel which in ordinary language is said to be empty.

Experiment 3.—Dip a tumbler with its mouth downwards gradually into a jar containing water (Fig. 1).

The water will not enter the tumbler, because the air in it cannot escape. In fact, the water in the larger vessel

gives way before the air shut up in the tumbler, rises higher and higher and runs over if the jar was full at first, just as if the tumbler and the air in it were together one solid body. Yet if you observe closely, you will see that

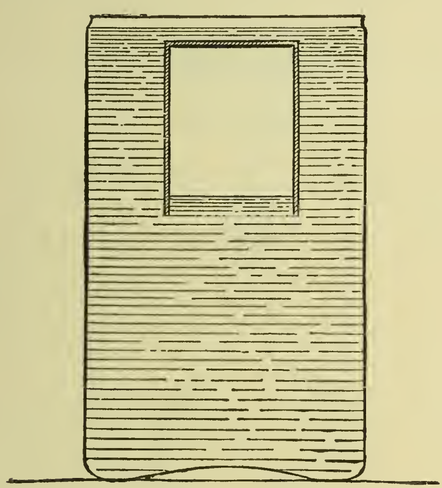

FIG. 1.

a small quantity of water will enter the tumbler; this happens because *air is a very compressible body*, and its bulk is slightly diminished by the pressure of the water in the jar around the tumbler.

It follows that a vessel cannot be filled with water unless the air in it can escape.

Experiment 4.—Fit a funnel which has a narrow tube firmly into a bottle by means of a perforated stopper, and pour water into the funnel (Fig. 2).

Since the air cannot escape, it will be found impossible to fill the bottle. In this experiment, as in the last, a small quantity of water enters the bottle because the pressure of the water in the funnel upon the air in the bottle diminishes the bulk of the air to some extent.

Experiment 5.—Close one end of a long and very thin piece of glass-tubing with the finger and push the other end through the water in the funnel down the tube. When the open end is inside the bottle remove the finger.

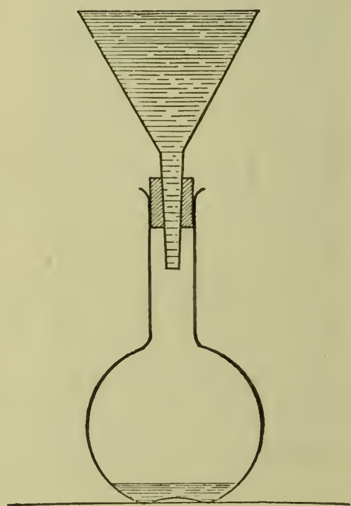

FIG. 2.

Now the air in the bottle can escape up the tube and may be felt as it rushes out, and the water will flow into the bottle to take its place.

QUESTIONS ON CHAPTER I

1. Describe an experiment which proves that we are surrounded by air.

2. How is it proved that work must be done in order to set air in motion ?

3. By which of our senses do we obtain a knowledge of the existence of air ?

4. Mention a number of different objects around us, and state by which of our senses we notice them.

5. How do we prove that a so-called empty tumbler is really full of air ?

6. How is it proved that we cannot fill a bottle with water unless the air can escape ?

7. How is it proved that air is compressible ?

CHAPTER II

AIR AND WATER COMPARED, SOLIDS, LIQUIDS, GASES

Experiment 1.—Take two similar tumblers, fill one with water up to the brim, cover both tumblers with glass plates, and place them side by side at some distance from you.

On looking at the tumblers, the level of your eyes being about half-way down them, they will appear very much alike, so that it is difficult to say which contains water and which air. Bodies behind them are easily seen, because air and water allow light to pass through them almost without hindrance; from this property they are both called *transparent* bodies (from the Latin *trans*, through; and *pareo*, to appear); they are also both nearly colourless. Water is, however, much less transparent than air, and when we look through a very thick layer of water it is found to have a bluish colour.

Experiment 2.—Lift both tumblers from the table on which they stand, and hold them in your hands.

Notice the difference in their weights. Water is a much heavier substance than air. *Water is found to be about* 770 *times heavier than air*, when equal bulks of both substances are compared.

Experiment 3.—Move first the flat side, then the edge of a plate of glass to and fro through water in a

pail or large trough (as in Chapter I, Experiments 1 and 2). Move the same plate also in both ways in air.

First, you will again notice the difference in the work required, according as you move the flat side or the edge. In the second place, observe that much more work is required for moving the plate in water than in air. This is chiefly due to the greater weight of the water, for the more substance or matter is moved the more work is required. But there is another reason. In moving your plate you separate one part of the air in the room, or of the water in the vessel, from another part. Now here a great difference between air and water shows itself. In the case of water no portion can be slid rapidly past any other portion which it touches without work being done; there is some action going on between the different parts of the water. You will gain a clearer idea of this kind of action if you consider what would happen if you were to move your plate through some oil or treacle. Now oil is lighter than water, yet you would have to do more work in moving your plate to and fro through the oil than through the water. Oil, treacle, and other such substances are said to be "sticky," or "viscous," which means the same, and what we imply by this property of viscosity, as it is called, is precisely that there is in such bodies as oil, treacle, or glycerine a greater mutual action between the particles of these liquids than in water and many other liquids, for example, in spirits of wine. Hence, when we wish to separate one portion of a liquid from another portion, we must make a less or greater effort, according to the nature of the liquid, besides merely moving the separated part of the liquid along. To this mutual action between the particles of a liquid the name *cohesion* (from the Latin *cohaereo*, to stick together) has been given.

In solid bodies, like wood and iron, this mutual action between the parts of the same body is enormously greater, and resists not only rapid motion but displacement of

any kind. Consider how much greater an effort is required to cut a bar of wood in two by means of a knife, as compared with that sufficient to separate the parts of the most sticky liquid. Hence we say that solids are characterised by *rigidity* (from the Latin *rigidus*, stiff). Between different parts of air such mutual action is insensible.

It follows that when by moving the plate in water we make one portion of the liquid slide past another, we overcome the mutual action between the parts of the liquid; this action becomes so great when the water freezes that we are unable to move the plate at all within the solid water, or ice, as it is usually called: on the other hand, no such action can be noticed, and hence no effort for overcoming it is required, when the plate is moved in steam, which is water in the state of a gas.

Experiment 4.—Drop a very little water upon a glass plate which has been wiped with an oily rag to make it greasy. Place another similar plate of glass above the water, and take the upper plate away again.

Here we can see the mutual action between the parts of a liquid very strikingly. The water when sprinkled over the lower plate splits up into small roundish drops; this is already a proof that the particles tend to cling together. After they have been squeezed flat, they will, when the upper plate is removed, by this mutual action resume the rounded shape again. No such tendency to keep together, as it were, exists in gases, but rather the reverse, as we shall see farther on.

Experiment 5.—Take off the glass plates from the two tumblers used in Experiment 1.

Observe that it is possible to tell where the top or surface of the water is; but where the air in the other tumbler ends it is impossible to say. The water has a well-defined surface, but there is no boundary between the

air in the tumbler and the air outside. From this it follows that the water takes the shape of the vessel in which it is, but has a bulk or volume which remains the same whether we keep it in this or any other vessel, provided we take no part of it away. The same water which fills one tumbler can be poured into a vessel of the same or a larger size, but by no possibility into one that is of a smaller size than the tumbler. It is different with air; for as in an open vessel no boundary is seen between the air inside and outside, we cannot in this case speak of a measurable, that is, definite bulk. Moreover, if a vessel contains air and is closed, we are still unable to speak of the air inside as having a definite bulk, because it will be shown hereafter that the quantity of air which may now fill a closed vessel before us would completely fill the interior of any other closed vessel, greater or smaller, if transferred into it.

It is also seen from Experiment 5 that neither the air nor the water has a definite shape of its own, for both take the shape of the vessel in which they happen to be. But if the water in the tumbler were made to freeze, we could turn the whole of it out, and either the whole, or a piece broken off the solid mass, would keep its shape as long as it remained solid water.

We have thus learnt to distinguish the three great classes into which all bodies in nature are divided. *Solids*, like ice, are characterised by rigidity, and a definite shape and bulk. *Liquids*, like water, are characterised by viscosity, and by possessing a definite bulk; but they have no independent shape. *Gases*, like air, are characterised by possessing neither independent shape nor definite volume.

QUESTIONS ON CHAPTER II

1. In what respects are air and water similar?

2. Describe experiments which prove that air and water have some similar properties.

3. Mention properties in which air differs from water.

4. Why is it more difficult to move a plate of glass through water than through air?

5. What is meant by *viscosity?* Give examples of liquids which are more viscous than water.

6. What is meant by *rigidity?* Give examples of rigid bodies.

7. What are the three great classes into which all bodies are divided? Give examples of each class.

8. How do gases and liquids differ from each other? In what respects do they agree?

9. How do liquids and solids differ from each other? In what respects do they agree?

10. Write out a little table showing the general properties which distinguish solids, liquids, and gases.

11. What is meant by a transparent body? Mention any solids, liquids, and gases which are transparent.

12. Mention any solids and liquids which are *opaque*, that is, not transparent.

13. How many times heavier is water than air, bulk for bulk?

14. A gallon of water weighs 10 lbs. How much does a gallon of air weigh?

CHAPTER III

PRESSURE IN LIQUIDS

Experiment 1.—Hold an empty tumbler, mouth upwards, firmly in your right hand, and push it slowly down into some water in a wide jar, until the water rushes into the tumbler and fills it.

At first when the tumbler touches the water no action is noticeable; but as you push it down you have to work against the action of the water, which is felt to press against the tumbler so as to push it upwards. This upward pressure becomes greater the deeper you push the tumbler down, but it apparently ceases when the mouth of the tumbler is sunk below the surface, and the water has rushed into it and filled it. The weight of the water in the tumbler will then press the tumbler as much downwards as the water underneath will press it upwards; this last pressure is therefore no longer felt. Indeed, we shall have now to prevent the tumbler from sinking downwards by reason of its own weight. It did not fall before, because the upward pressure of the water below it is greater than the weight of the tumbler together with the air it contains.

Experiment 2.—Force a vessel of glass or tin, having a small hole in its bottom, down into some water, in

the same way as in Experiment 1, but quickly, and not so far as to allow water to enter at the top (Fig. 3).

A jet of water spouts upwards through the hole. By your downward pressure you have set water in motion, and a wall of water surrounds the vessel which presses downwards by reason of its weight. But clearly it does not only press upon the water just under it; for the water spouts upwards through the hole until it is at the same level inside and outside. Hence the downward pressure

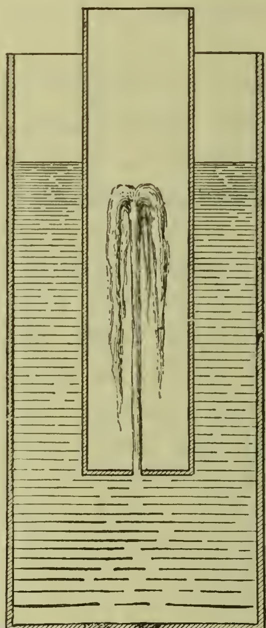

Fig. 3.

must be causing a pressure at the hole, or, as it is expressed, it must be "transmitted" to the portions of water underneath the bottom of the vessel.

Both the preceding experiments prove one of the chief properties of liquids, viz. that *if pressure is applied to any part of a liquid this pressure will act in all directions, downwards and sideways as well as upwards.*

Liquids are not compressible, or at any rate only very slightly; air, as we have seen in Chapter I, is very compressible. When pressure is applied to air enclosed in a vessel its bulk is diminished, and the effect of the pressure is felt in all directions as completely as is the case in substances which are incompressible, like water. The reason of this is that the effect of pressure is to make those portions of a substance where the pressure is applied move; now in air and water every part is able to move freely in every direction. On the other hand, in solid bodies the parts are kept together by their rigidity, and are thus prevented from moving freely; hence when pressure is applied to a solid body it is not transmitted in every direction, but as solids are always somewhat compressible it may produce a diminution of bulk, especially when the pressure is very great, or may cause more or less considerable alterations in the shape of the solid.

Experiment 3.—Take a piece of wide glass-tubing, and cut out a round piece of cardboard (still better, of leather) a little larger than the bore of the tube. Fix a string to the middle of the cardboard disk, pull the string through the tube, hold the string, and plunge the tube into a jar of water (Fig. 4).

When the paper disk is a few inches below the surface you need no longer hold the string; the upward pressure of the water will be sufficient to keep the disk in its place.

Experiment 4.—Pour water slowly into the tube until it nearly reaches the level of the water outside.

Observe that the paper disk will fall off when the water inside is a little below the level of the water outside; or

more accurately, when the upward pressure of the water in the jar against the paper is just balanced by the downward pressure of the water in the tube together with the

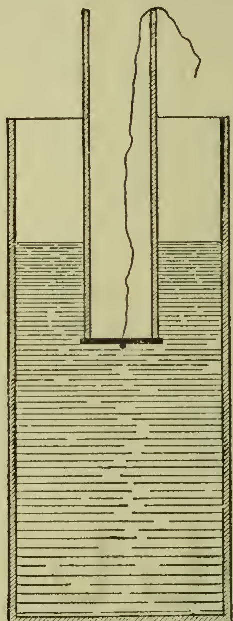

FIG. 4.

weight of the disk, a little additional water poured into the tube will make the disk go down. The less the weight of the paper disk the more nearly will the level inside have reached the level outside the tube when the disk falls.

Experiment 5.—Lower two tubes, of the shapes *a* and *b* in the figure, each containing a little mercury at the bend, into water (Fig. 5).

Observe that the deeper each tube is let down into the water the more the mercury is pushed up in the longer branch by the pressure of the water acting on the mercury at the open end. Further, the presence of the water in

the tube *a* acts downwards, in *b* it acts sideways; but when both tubes are at the same depth in the water the

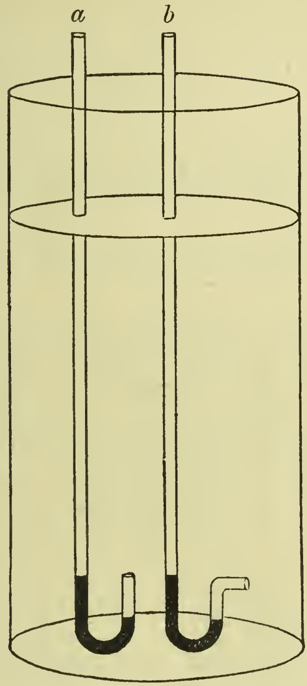

FIG. 5.

mercury is pushed up in both cases to the same height. Hence these pressures must be equal; and they are at the same depth.

QUESTIONS ON CHAPTER III

1. Describe what you notice when pushing an empty tumbler with its mouth upwards into water.

2. Why would not the tumbler fall down through the water of itself if you were to take your hand away while it was only a few inches down in the water?

3. Describe what happens when a vessel with a hole in the bottom is pushed into a jar of water.

4. What important fact about liquids is proved by these two experiments?

5. Describe an experiment which shows still better the existence of upward pressure.

6. How can we show that in a liquid the pressure becomes greater the greater the depth?

7. By what experiment can we compare the pressure sideways with that downwards at the same level?

8. Why does a bucket of water appear lighter while it is still in the water than when out of it?

CHAPTER IV

PRESSURE OF AIR

Experiment 1.—Fill a tumbler with water and cover it with a piece of stiff paper, of the same shape as the mouth of the tumbler but a little larger. Let the fingers of your left hand gently press upon the paper, and with the other hand quickly turn the tumbler upside down. Hold it before you in this position, and remove the fingers of the left hand from the paper.

No liquid will run out, or at most only a few drops. We know that without the paper cover the water would not remain in the tumbler in the position in which it is held. We may be sure also that the light paper cover would fall down by its own weight if there were no water, and still more so if the water itself tended to fall. Hence we must conclude that pressure acts upon the outside of the paper which is more than enough to hold up both the cover and the water, and to prevent them from falling. This pressure can only be due to the air around us. The tumbler with the paper, and the water in it, is in this experiment dipped into air, just as in Experiment 3 of Chapter I a tumbler filled with air was dipped mouth downwards into water. Air, like every kind of matter, has weight, and by reason of its weight exerts pressure upon all bodies surrounded by it. In our case the tumbler is surrounded by a very high wall of air, and as air transmits

pressure upwards, downwards, and all round, like water, the pressure of this high wall acts upwards on the paper, preventing it, and the water behind it, from falling down. Although air is a very light body compared with water, yet it exerts a great pressure, because the atmosphere reaches to a great height.

Every portion of air around us taken by itself is under the action of this pressure all round it. Hence if the tumbler contained air instead of water, the paper would fall off if the tumbler were held mouth downwards, because the air in the tumbler presses behind the paper quite as much as the air in front of it, and the paper falls simply by its own weight. The reason given would lead us to expect that a tumbler full of water could be held upside down without any water running out, even if there were no piece of paper over the mouth. Nor is our conclusion absolutely incorrect; but in practice it is impossible to hold a tumbler full of water so level or so still that the pressures of air and water are acting in the same way at every point. If the tumbler is inclined ever so little the pressures vary from point to point, and air forces its way up at one point while water flows out at another. The paper, in our experiment, prevents this even if the tumbler is not held quite level.

Experiment 2.—Close one end of a long and very narrow glass tube and fill it with water. Close the open end with the thumb, turn this end downwards, hold the tube quite perpendicularly, and remove the thumb.

In this case there cannot be much variation of pressure from point to point, because the surface exposed is very small; and the tube being very narrow, air and water cannot pass one another so conveniently as in a wider vessel, hence the water will remain in the tube, maintained by the pressure of the air.

The pressure of the air is able to support in the way shown by this experiment a very long column of water; indeed our tube might have a length of about 34 feet, and the weight of such a pillar of water would still be supported by the pressure of the air.

Experiment 3.—Fill a bottle with water, close it with the palm of your hand, and insert it in a vessel of water. Remove the hand (Fig. 6).

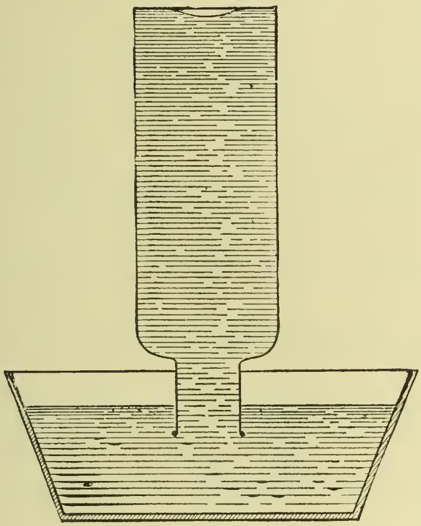

FIG. 6.

No water will leave the bottle when the hand is withdrawn. The pressure of the air on the open surface of the water in the vessel is transmitted through the liquid in all directions and maintains the water in the bottle.

Experiment 4.—Bend a tube into the shape of Fig. 7. Pour a little coloured water into it; attach the end *a* to an ordinary gas-burner by means of a short india-rubber tube and turn on the gas.

The gas rushes into the apparatus at *a* and presses upon the liquid at *d*; the liquid sinks at that point and rises at

c. After a short time the liquid will be at rest, and stand an inch or two higher in the open branch of the tube than in the branch connected with the gas. Now since the pressure of the air acts upon the liquid through the open end *b*, it follows that the pressure of the gas must be a little greater than the pressure of the air; this difference of pressure is measured by the height through which the

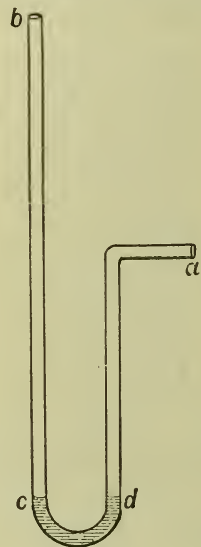

FIG. 7.

liquid is raised in the open tube above that in the branch connected with the gas.

Such a bent tube containing liquid may be employed for comparing the pressure of a gas with that of the air, and is called a *pressure-gauge.* When thus used both branches are generally divided into inches and fractions of an inch, and instead of water a heavier liquid, for example mercury, may be used when great differences of pressure are to be measured.

QUESTIONS ON CHAPTER IV

1. Describe how we may prove that the air around us exerts pressure upon all bodies.

2. How is this pressure caused?

3. Explain in what respect the pressures exerted by gases and liquids are similar.

4. What is the object of placing paper over the tumbler in Experiment 1?

5. Why does no water run out when a narrow tube is used instead of a tumbler?

6. What height of water could the pressure of the atmosphere support?

7. Why does the water rise when you put one end of a tube into water, and suck at the other end?

8. How can you measure the pressure of the gas in the gas pipes?

9. How is it proved that the pressure applied to a gas is transmitted in all directions?

10. What would happen in Experiment 4 when the gas is turned on if the pressure of the air were greater than that of the gas?

CHAPTER V

MUTUAL ACTION BETWEEN SOLIDS AND LIQUIDS

Experiment 1.—Dip a sheet of paper into water, take it out again, and let the water drip back into the vessel. Repeat the same experiment with a plate of glass.

Observe that some water clings to the paper, and also to the glass; both become wet, the paper more than the glass. We say that in such cases there is *adhesion* (from the Latin *adhaereo*, to cling to) between the liquid and the solid. A hand dipped into water and withdrawn is covered with adhering drops. But if our hand were covered with a layer of wax, or any fatty substance, and then dipped into water, very few drops would adhere. Thus there are degrees of adhesion between the same liquid and different solid bodies.

Experiment 2.—Dip your finger, a glass tube, a piece of sealing-wax, and a small piece of bright lead successively into mercury contained in a glass or china dish.

Neither the finger, the glass tube, nor the sealing-wax will show any trace of liquid on their surfaces, but drops of mercury will adhere to the lead. Here it is only between the lead and the mercury that there is adhesion sufficiently strong to cause the surface of the solid to be moistened by the liquid. Among other ordinary metals all except iron are moistened by mercury.

Experiment 3.—Throw a pinch of common table-salt into half a tumbler of water, and stir it with a glass rod or spoon.

The white grains of salt gradually become invisible; the solid salt is converted into a liquid, which is mixed with the water, as shown by the taste of salt which the water assumes. We call this a *solution* of salt in water, while the water is said to be the *solvent.*

We know that in solid salt the parts are kept together by mutual action, because an effort is required on our part if we wish to break or crush even the smallest grain of salt. This mutual action must clearly cease when the solid becomes liquid salt. We know also that salt becomes moist when dipped into water, hence there must be adhesion between water and salt. We therefore conclude that when a solid is dissolved, as in this case, in a liquid, the cohesion is overcome by adhesion. The liquid, as it were, pulls every particle of salt away from every other particle to which it was formerly attached by cohesion, and takes it to itself.

Experiment 4.—Continue adding small quantities of salt to the water, stirring between each addition, until no more will dissolve.

It is thus found that there is a limit to the quantity of salt which the water in the tumbler will dissolve. The more we add the longer it takes for the last portion to dissolve, until the limit is reached and the salt added remains in the solid state. Such a solution is called a *saturated* solution; a solution very near this point is called *concentrated;* one which contains little of the soluble substance is called a *weak* solution.

Careful experiments have shown that 100 parts by weight of water dissolve about 35 parts of salt.

Experiment 5.—Pour into a second tumbler as much water as there is saturated salt-solution in the tumbler used in the last experiment. Place an egg first into water, then into the salt-solution.

The egg floats in the salt-solution but sinks in the water. We conclude from this that the egg is lighter than the saturated solution but heavier than water; and further, that water in which salt has been dissolved thereby becomes heavier. For we know that the egg floats in the salt-solution because the weight of the liquid around it presses it upwards, and this upward pressure is greater than the weight of the egg. But as the egg sinks in ordinary water, the weight of the water around it, and consequently the pressure that it exerts upwards, must be less than the weight of the egg, as otherwise the egg would float; hence salt water is heavier than ordinary water.

QUESTIONS ON CHAPTER V

1. What is our object in dipping paper and glass into water ?

2. How is it that the paper and the glass both become wet ?

3. Is there any difference observable between the behaviour of the paper and the glass ?

4. What is said to be the cause of both being moistened by the water ?

5. What would happen if the paper were first dipped in oil and then in water ?

6. How can we prevent glass from becoming wet when it is dipped in water ?

7. Describe the action of lead, iron, glass, and sealing-wax on mercury.

8. What is meant by a solution ? What by a solvent ?

9. What is supposed to take place when a solid body is dissolved in a liquid ?

10. What is meant by a *saturated*, a *concentrated*, and a *weak* solution ?

11. To which of these three classes would you reckon sea-water, which contains about $3\frac{1}{2}$ lbs. of solid salts in 100 lbs. of water ?

12. How much salt can be dissolved in 200 lbs. of water ?

13. How can we prove that salt water is heavier than ordinary water ?

CHAPTER VI

SOLUBLE AND INSOLUBLE SUBSTANCES—FILTRATION

Experiment 1.— Fill three tumblers of equal size exactly one third full of ordinary water. Put into the first tumbler a pinch of salt, into the next a pinch of sugar, into the third a pinch of sand. Stir for a few minutes with a glass rod or spoon.

All three substances will be seen to fall to the bottom, they are therefore heavier than water. As we stir the salt and the sugar will disappear; they are *soluble* in water: the sand will remain solid as it was when thrown in, falling to the bottom as soon as we cease stirring; sand is *insoluble* in water. We can now take out the sand again from the water, but not the salt and sugar.

Experiment 2.—Pour off as much clear water from the sand as you can into another tumbler; the remainder, including the sand, pour into a shallow dish.

We have now separated the sand from the greater part of the water. On tasting the water we shall further find that the sand has not acted on it as we shall find the salt and the sugar have acted on the water in the first two tumblers, for they have given in the one case a salt taste to it, in the other a sweet taste. Thus we learn that only those substances can be distinguished by the sense of taste which are soluble. We may now try to pour off a

little more clear water from the dish, but we shall not succeed in removing all. Some water will have to be left in the dish if we wish to keep all the sand in it; some will adhere to the grains of sand even if we were able to keep them back in the dish by some means while pouring off the last drops of the water. The water may, however, be very conveniently separated from the sand by the operation of *filtration*. There are certain substances, such as unglazed paper and felt, which allow liquids to pass through them but not solid bodies, even if very small.

Experiment 3.—Set up a funnel in a suitable stand, place under it a tumbler or other vessel, fit into the funnel a filter-paper (prepared as described in the Appendix), and pour the contents of the dish with the sand into the funnel.

The water runs through the paper into the tumbler underneath, while the sand remains on the filter. There will be water adhering both to the filter-paper and the sand. We allow the whole to stand some time, and we shall find paper and sand quite dry. We say in this case that the water has *evaporated*, that is, changed into an invisible gas, like air, with which indeed it has mixed.

We have thus learnt not only how to recover a substance like sand, insoluble in a liquid when it has been mixed with it, by filtration, but also how different substances, some of which are soluble while others are insoluble in the same liquid, may be separated from each other. Thus suppose sugar and sand were mixed up together in the solid state. We have seen that sugar is soluble in water, while sand is not. Hence by throwing our mixture into water the sugar will dissolve in it, and after filtration we shall have the sand on the filter-paper, while the solution of sugar will have run through into any vessel placed beneath the funnel.

Filtration is a very important operation, and of great

practical utility in purifying water and other liquids in which solid bodies are floating, or, as it is expressed, are *suspended* (from the Latin *suspendo*, to hang one thing to another).

Experiment 4.—Continue adding pinches of salt and sugar to the two tumblers left from Experiment 1.

You will again come to a limit, when the water will cease to dissolve either. But observe that much more sugar will be dissolved by the water in the one tumbler than salt in the other. Hence there are degrees of solubility. Sugar is more soluble in water than salt.

Observe that each solution has a decided taste, one of salt, the other of sugar; also that one is very liquid, like water, while the other is somewhat sticky. Keep both for further experiments.

QUESTIONS ON CHAPTER VI

1. How would you proceed to obtain clear water from a brook after rain has been falling?

2. If two tumblers containing solutions of salt and sugar respectively were put before you, how would you decide which was the one and which the other?

3. If an ounce of sand is thrown into a pint of water, how would you get out the sand and show that it is unchanged?

4. What is meant by suspended matter?

5. Which is more soluble in water, sugar or salt? How would you prove your answer most accurately?

6. Mention some substances you know which are soluble, and others which are insoluble in water.

CHAPTER VII

EFFECT OF HEAT ON SOLUBILITY—EVAPORATION

Experiment 1.—Pour off the clear saturated solution of salt made in Experiment 4, Chapter VI, into a beaker, place it upon a tripod stand, and apply heat till the solution boils gently. Add pinches of salt while the liquid boils.

Notice that the salt added remains undissolved, provided that care was taken to have the solution saturated when cold. Hot water will dissolve about the same quantity of salt as cold water.

Experiment 2.—Treat the solution of sugar in the same way, adding pinches of sugar while it boils.

The solution which was saturated when cold will dissolve a considerable additional quantity when hot. Indeed it is a general rule that a liquid when hot will dissolve more of any solid substance than when cold. Some substances, ordinary salt amongst them, form an exception to the rule.

Experiment 3.—Divide the saturated solution of salt left from Experiment 1, after pouring it off from the undissolved salt, into two parts. Pour one part into a china dish, the other into a tumbler. Place the china dish upon a tripod and heat gently.

When a dish of water is left to itself the water gradually disappears, and we say that it dries up, or evaporates. What really happens is that it becomes a gas, that is, a body like air, as in Experiment 3 of the last chapter, and mixes with the air. This gas is usually called steam, or vapour of water, and we can transform any quantity of water into steam more readily still by boiling the water. In our present experiment observe how the level of the liquid in the dish becomes lower and lower, and how below the original level fine white lines of salt are forming all round. This is what we should expect. We convert the water into steam, but not the salt in it; this remains behind, and as the water in the dish is already saturated the solid salt makes its appearance in the place from which the water has gone. Finally, we shall reach a point when all the water is driven off, and the dry solid salt is left behind. If we have paid attention to the actual quantity of salt put in, we shall find that not a grain of it is missing.

We thus learn that a dissolved solid can be recovered by the process of evaporating the liquid in which it is dissolved. Moreover, evaporation enables us to decide the question whether a given liquid contains any solid substance dissolved or not. If water which is perfectly pure be evaporated, it will of course not leave any solid as a so-called *residue* in the dish.

Experiment 4.—Add a few pinches of sugar to the second portion of salt-solution.

The sugar will readily dissolve. Thus a liquid although saturated with one kind of substance may be capable of dissolving some of another kind of substance in addition.

If we pour this mixed solution into a dish and heat it gently we may expect that as the water diminishes a certain quantity of salt will be deposited along the top, but no sugar; for the liquid was not saturated with sugar,

which is the more soluble substance of the two, and therefore remains in solution, and this is indeed what happens. Thus we see how two different substances in solution, of which one is more soluble than the other, may by gradual evaporation be partly separated.

Instead of proceeding in this manner the dish may be set aside in a place free from dust (a cupboard is best); although no heat is applied granules of salt will make their appearance in a few days, in consequence of the gradual evaporation of the water. Some of these granules, if carefully looked at, will be seen to have regular shapes, with flat shining faces and sharp edges. These granules are now called *crystals* of salt, and the salt is said to crystallise out from its solution. If the liquid is boiled the motion of the boiling mass prevents the formation of the sharp edges and smooth faces; hence we obtain the solid as an amorphous (from the Greek *a*, without; and *morphe*, shape) mass or powder, and not in a crystalline form.

Experiment 5.—Pour off the saturated sugar-solution left from Experiment 2 into a dish and heat it gently.

The sugar-solution becomes thicker and thicker and gradually changes its colour, first to a deep yellow and then to brown, while at the same time the mass becomes harder. The sugar has now undergone a greater change than merely one of form; it is in reality no longer sugar, but it is now called *caramel*, and is in this state employed for various purposes for which sugar could not be used. If a small portion is thrown into water it will dissolve, but give a solution which is coloured brown or deep yellow. If the original solution be further heated, still greater changes may be observed, as will be seen in the next lesson.

QUESTIONS ON CHAPTER VII

1. What effect has heat upon the power of a liquid to dissolve solid substances ?

2. State in what respect ordinary salt forms an exception to the rule.

3. How would you proceed to get back a quantity of salt which has been dissolved in water ?

4. Of two samples of water before you one is perfectly pure, the other is impure. How would you decide which is pure and which is impure ?

5. A solution contains sugar and salt. How could you prove it by experiment ?

6. Explain the meaning of the following words : *evaporation*, *crystal*, *amorphous*.

7. Write out all the properties in which salt and sugar differ. What properties have they in common ?

CHAPTER VIII

ACTION OF HEAT UPON BODIES—CHEMICAL ACTION

Experiment 1. — Place a few scraps of wood in a test-tube, and heat the part containing the wood above the flame of a spirit-lamp, holding the mouth of the tube a little lower than the closed end.

The wood does not burn with flame as it would if heated in the open air. It becomes charred and blackened, while at the same time steam and vapours are given off, which collect on the cold sides of the glass, partly as water, partly as a brownish tarry liquid. By being heated the wood has been broken up, or decomposed (from the Latin *decompono*, to separate the parts which make up a whole thing) into other substances. These substances are in all respects quite different from wood, and yet they have been obtained from it by the action of heat. The black residue in the test-tube can easily be recognised as ordinary charcoal. No different body can, however, as far as we know at present, be obtained from the charcoal. Such a substance is called a *simple body* or an *element*. Wood, on the other hand, from which substances different from it can be obtained, is not an element, but a *compound body*, or simply a *compound*. The tar and water, which you see in the tube, are also compounds.

Experiment 2.—Repeat the previous experiment, but provide the test-tube with a perforated stopper fitted

with a short piece of glass-tubing, drawn out to a fine opening at the free end. After heating for a few minutes apply a light to the end of the tube (Fig. 8).

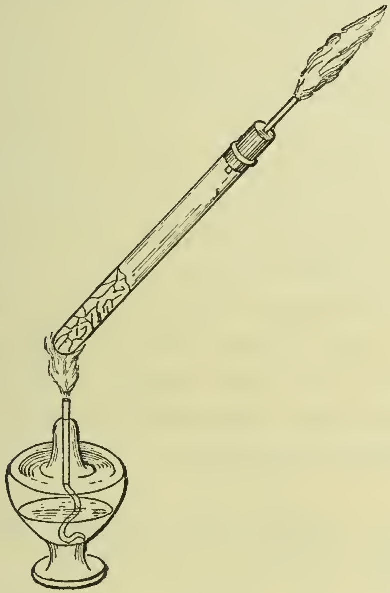

FIG. 8.

Observe that the substance which rushes out of the tube can be lighted like ordinary gas, and burns with a bright flame. Thus when wood is decomposed we obtain a solid body, charcoal, water, a brown liquid, tar, and an inflammable gaseous body differing from air, which, as we know, does not burn, but similar to the gas used for lighting. Indeed, ordinary gas for lighting is made in a very similar way by heating coal, which is nothing else but the remains of plants which, like the tree from which we obtained the wood for our experiments, grew at one time on the surface of the ground, but which have been buried deep in the earth, and have in the course of time undergone such changes that it is not at once seen that coal is really vegetable matter.

When we see wood thus taken to pieces as it were, we naturally ask: Will these different substances again make wood? They will, no doubt, but in the case of wood we have not yet succeeded in forming it from the simple bodies of which it consists. In many other cases we have been able to decompose a compound into its elements, to carefully collect these elements in the same proportions as we find them, and by proper means to form the original body again. In all such cases there must be some mutual action between the elements which keeps them together so as to form a substance different from themselves; this kind of action is called *chemical action*, or *chemical affinity* (from the Latin *affinitas*, connection or attraction). It differs from all other actions going on between matter in that the substances between which chemical action takes place each give up their individual properties to form new bodies with different properties.

Experiment 3.—Repeat the previous experiment, but take a little sugar instead of the wood.

The result is very similar. An inflammable gas is given off, while charcoal is left behind as a black mass. Observe that the sugar melts, that is, becomes a liquid, before being decomposed. As a consequence the charcoal has a glossy appearance.

Heat thus not only breaks up compound bodies, as we see every day in a coal fire, but in some cases changes their external form. A solid when heated becomes liquid; a liquid when heated becomes a gas. Everybody knows examples of these changes—ice, which is a solid, melts in a warm room and forms water; water, when heated, or even when left to itself in an open vessel, evaporates, that is, becomes steam. Thus heat overcomes cohesion.

Experiment 4.—Heat some tin in a small china dish until melted.

Tin when being heated melts sooner than is the case with most other metals. Observe that after it is melted a kind of film, which may be coloured yellow, red, or even blue, forms on the surface. This may be carefully removed to the side of the dish by a spoon, and the surface of the metal beneath will appear perfectly bright and silvery for a short time; but very soon it will again become coloured, and a new film may be removed as before. When the dish is allowed to get cold we may see that the substance thus removed differs in appearance from the metal itself; it is not only coloured but has an earthy powdery appearance. It is indeed no longer pure tin. In this case also a new body has been formed, not by breaking up the tin, which is a simple body, but by chemical action between the tin and the air surrounding it. What is really going on in this action will be studied more fully in the tenth and some future chapters.

Experiment 5.—Heat, in the flame of a burner, first a bright piece of iron or steel, then a bright piece of copper.

Neither of these bodies will melt, because the flame is not hot enough for the purpose. If you had a hotter flame at your command they would melt just as the tin did. Observe, however, that both these metals also become covered with coloured films, which can be scraped off when they are cold with a knife or sandpaper. Copper and iron are simple bodies; the film formed is a compound of the metal and some part of the air. Recollect how tarnished a bright copper vessel becomes when kept for some time; think of the brown powder forming on the surface of iron, called *rust*. All these are examples of chemical action between the metals and the air around them.

QUESTIONS ON CHAPTER VIII

1. Describe what happens when wood is heated in a test-tube.

2. Why is charcoal called a simple body? Why is wood called a compound body?

3. Mention three different substances produced when wood is heated in a test-tube.

4. Mention any other substances which resemble wood in the action of heat upon them.

5. In what respect is the experiment with sugar similar to that with wood? In what respect different?

6. Describe what happens in each case, when tin, copper, and iron are heated. In what respect are the results of the experiments with these three metals alike, in what respect unlike?

7. Describe the effects produced when bodies are heated, as far as you know them.

8. Which of the following substances is an element, which a compound: *sugar*, *tin*, *charcoal*, *iron*, *rust*, *copper*, *wood?*

CHAPTER IX

ACTION OF HEAT UPON BODIES—EXPANSION

Experiment 1.—Fill a glass flask up to the brim with water, place it on a tripod, and heat it over a spirit flame or gas-burner.

As the water gets warm some of it will run over, and this will go on as long as the water is heated. When the flask is so hot that it is no longer possible to grasp it with the hand, remove the flame. Observe that as the water cools it will shrink and now stand much lower in the flask than it stood before heating.

The experiment shows that when water is heated it occupies a greater space than before, for part of it has run over. It further proves that hot water when cooled occupies a smaller space than before. Water *expands* when heated, and *contracts* when cooled.

In order to observe this expansion more accurately, stop the mouth of the flask with a cork or india-rubber stopper having a hole in the middle of it, and a glass tube which fits the hole tightly passing through it (Fig. 9).

Experiment 2.—Fill the flask (Fig. 9) with water, so that it stands as at *a* when the cork is firmly pushed in. Heat it as in Experiment 1.

The water, which in the previous experiment was displaced from the flask, now rises in the tube, and this rise is

greater in proportion to the smallness of the bore. By this means, if the tube is very narrow, a very slight rise can easily be seen, and from the fall or rise of the top of the liquid in the tube we may, by successively putting our bottle into two liquids and observing the movement of the top of the liquid in the tube, decide which of the two is the hotter, or rather which is hotter or colder than the

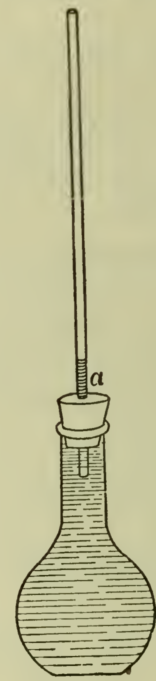

Fig. 9.

stoppered flask, even in cases where after touching them with the hand we should still be in uncertainty. This is however more accurately done by means of particular instruments called *thermometers* (from the Greek *therme*, warmth; and *metron*, a measure), which in their action and form resemble our bottle, being however considerably smaller and more delicate.

Experiment 3.—Fill two test-tubes of equal size to within an inch of their mouth, one with water, the other with alcohol. Support them upright inside a beaker, and fill the beaker with hot water up to the top of the liquid in the test-tubes.

Observe that both liquids rise in the test-tubes, but the alcohol rises more than the water. All liquids, indeed all bodies, with a few rare exceptions, expand when heated and contract when cooled. But the amount or rate of expansion is not the same. Every solid and liquid substance has its own rate of expansion, which forms a distinct property of that substance, and no two solid or liquid substances in nature appear to expand exactly by the same amount when equally heated. Gases, on the other hand, expand all at the same rate. Solids as a rule expand much less than liquids, liquids less than gases. The expansion of solids is so small that special contrivances are required for making it obvious. One of the most common consists of a metal ball which just passes through a metal ring when cold; when the ball is heated it no longer passes through the ring, because the ball has expanded while the ring has kept its former size. On the other hand, if the ring is made slightly smaller than the ball, so that the ball will not pass through it, it will do so after the ring has been heated.

Experiment 4.—Dip the open end of a glass tube provided with a bulb into water and heat the bulb gently (Fig. 10).

Bubbles of air will escape from the interior of the tube through the water. There is not room enough in the bulb for the heated air; it requires a larger space than it did while cold, hence in consequence of being heated it has expanded.

If the lamp be removed the air remaining in the tube and bulb will contract on cooling, and the pressure of the

air outside will drive water up into the tube, replacing the air which has been expelled. Such an apparatus, like that used in Experiment 2, may be used as a thermometer, and

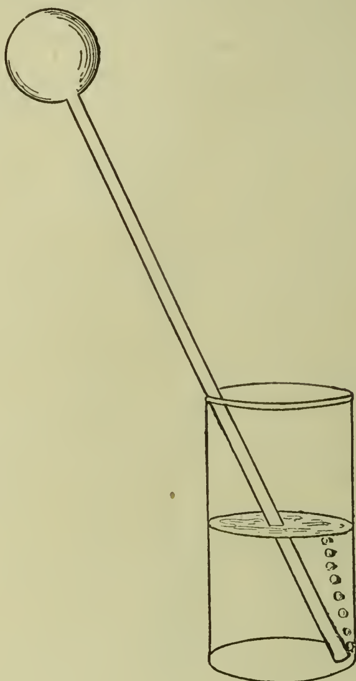

FIG. 10.

is called an *air-thermometer*. When the bulb is heated the liquid in the tube falls, because the air in the bulb expands; when the bulb is cooled the air in it contracts and the liquid rises.

Experiment 5.—Place a small moist piece of cloth upon the bulb of the air-thermometer.

The rise of the liquid shows that the air in the bulb contracts, that is, it is being cooled. Let us consider what is going on. The moist cloth is neither colder nor warmer than all other bodies round it, including the thermometer, for there is no reason why it should be either colder or

warmer than anything else near it. But the piece of cloth contains some water which evaporates, that is, gradually becomes steam. We know that the piece of cloth, if left some time where it is, would become quite dry. But we know also that if we wish to form steam from water quickly we must heat the water; in this special case we should have to apply heat to the moist piece of cloth, if we would dry it more rapidly than it would dry without our assistance. From these facts we may justly conclude that even when water evaporates slowly heat is required for the changing of water into steam, and is taken away from the water itself and from bodies which are close to it. In this case the heat is taken from the bulb and the air within it, as is proved by the contraction of the air, which shows that it is getting colder.

Experiment 6.—Drop a little alcohol upon the piece of cloth without removing it from the bulb.

The alcohol evaporating more readily than water, the heat required for the evaporation is taken more quickly from the bulb and the air near the cloth, hence the air contracts, and the liquid rises more rapidly than in the case of water.

There are some liquids which evaporate still more easily than alcohol, for example benzene, ether, and others. If a few drops of ether are let fall upon the cloth, the cooling effect upon the thermometer, due to evaporation, is so great that the liquid rises rapidly and flows into the bulb itself.

QUESTIONS ON CHAPTER IX

1. Describe a means of easily proving of any given liquid that it expands when heated.

2. How could you prove that a bottle filled with hot water must be lighter than the same bottle filled with cold water?

3. Describe a method of comparing the expansion of several liquids with one another.

4. If you had only one stoppered bottle, how could you compare several liquids as regards their rate of expansion?

5. If you breathe for a short time upon the bulb of the air-thermometer used in Experiment 4, what will happen? Give reasons for your answer.

6. Could you by any means make the liquid go right up to the top of the bulb of the air-thermometer, and fill it completely? Give reasons for your answer.

7. Why is it undesirable to have the liquid filling part of the bulb of the instrument if we wish to use it as a thermometer?

8. In Experiment 2 the liquid may be seen at first to fall slightly in the tube when the heating begins. Explain this.

CHAPTER X

ACTION BETWEEN AIR AND OTHER BODIES

Experiment 1. — Moisten the inside of a tall and wide glass jar, and sprinkle some clean iron filings over the moistened surface. Place it mouth downwards over water in a plate, and leave it for a few days.

The iron filings will gradually grow rusty. At the same time the bulk of the air in the jar will become less, and the water will rise slowly until it fills about one-fifth of the volume originally filled with air. If we were to leave the jar for some time longer, we should find that the bulk of the enclosed air will not be further lessened.

The iron has undergone some change; it has become covered with a substance which is a brown powder, called rust. Iron is necessary for the formation of rust, for although other metals may be substituted for iron in this experiment, no such brown powder will be produced. Again, rust is very different from iron, as is easily seen. It seems to be iron changed in some way. But has the air, besides losing some of its bulk, undergone any other change? This may be decided as follows:—

Experiment 2.—Slip a flat plate of glass under the mouth of the jar, lift it out of the water, and place it on the table mouth upwards. Remove the plate and plunge a lighted taper quickly into it.

The taper will immediately cease to burn. The air appears to have given up to the iron some part of itself, which must be present if the taper is to burn in the air. If we fill the jar with water and pour it out again, we shall fill the jar with air which has not been acted on by the iron. A lighted taper now introduced will not go out.

Now whenever this experiment is made with different quantities of air, we shall always find that about one-fifth of the quantity present is removed, provided that a sufficient supply of iron has been placed inside the jar, and proper time allowed for the action. Hence we may conclude that when iron rusts a new body is really formed, and that the air gives up to some of the iron a certain fixed proportion of it, which possesses the property of being necessary for the formation of rust. This part of the air, as we have just seen, has different properties from that which is left behind; hence we may again conclude that air is made up not of one kind of gas but of two at least, one allowing a candle to burn in it, the other not; one capable of chemical action upon iron, the other not.

Our conclusions will be still further confirmed as we go on, for we shall be able to prove that rust consists of iron and a certain gas which is found in air; these two elements being held together by chemical action, losing their own peculiar properties, and forming by their union a compound having properties differing altogether from those of either.

The gas which in this experiment combines with the iron and the presence of which in air enables the taper to burn is called *oxygen*. The gas which has no action upon the iron, and does not enable the taper to burn in it, is called *nitrogen*. From our experiment we may conclude that of a given bulk of air about one-fifth is oxygen and four-fifths nitrogen.

When tin, copper, and iron were heated in the experiments of Chapter VIII, their surfaces became covered with films; these consist of nothing else but chemical compounds of the metals with oxygen. The gray film which soon tarnishes a recently-cut surface of lead is similarly a compound of lead with oxygen, or an *oxide* of lead. We cannot readily obtain the oxygen from these bodies, but we can do so in the case of the compound which the metal mercury, or quicksilver, forms with oxygen. When mercury is heated for some time in the air to a point just below that necessary to make it boil, it becomes covered with red scales, which are an oxide of mercury. Indeed the experiment, which, however, takes several days for its completion, is very similar to that with iron in Experiment 1, if the mercury be heated in a closed flask. In that case the bulk of the air in the flask after the experiment is finished will be found to have diminished by one-fifth, while nitrogen is left behind. When this oxide of mercury is heated strongly it breaks up into mercury and oxygen.

Experiment 3.—Heat a little red oxide of mercury in a small test-tube.

Knowing that the oxide is formed by the chemical union of mercury and oxygen, we shall see it break up again into these two elements. The mercury will by the action of heat become converted into vapour of mercury, just as water is converted into vapour of water; and, like steam, the vapour of mercury will in the upper colder part of the tube become a liquid again. We shall see a kind of mirror there formed of shining drops of quicksilver. The oxygen is invisible, but that some gas escapes and that it is not like air may be shown by holding the mouth of the test-tube close to a burning taper: the flame is blown aside, but increases considerably in brightness. We may go further and put inside the tube a splinter of wood with

one end nearly charred, so that a glowing spark is left at it: the wood will burst into flame. Thus we may conclude that oxygen is essential to the ordinary burning of a body with flame, and that flame is brighter in oxygen than in air. We have already seen that burning does not go on in air from which the oxygen has been removed. Oxygen is hence called a supporter of combustion (from the Latin *comburo*, to burn completely); nitrogen is not a supporter of combustion.

As we proceed further we shall see more and more that whenever bodies burn in air, the oxygen of the air combines with some of the *elements* of the burning body to form new compounds. Indeed the rusting of iron is simply a slow burning of iron without visible flame, in which a new body is formed, oxide of iron or rust, containing iron and oxygen, which are held together by that kind of mutual action which has been called chemical affinity.

Every such chemical action in which a body unites with oxygen is called an *oxidation*.

QUESTIONS ON CHAPTER X

1. Describe what happens when iron filings are kept in a jar over water.

2. How do we prove that air contains at least two different kinds of gases ?

3. Give the names of the two gases, and state in what respects they differ.

4. What is the proportion in which the two gases are present in air ?

5. How much of either gas would you expect to find in 100 cubic feet of air ?

6. What is the substance which covers the surface of many metals when exposed to the air ?

7. What elements are combined in lead oxide ?

8. How is mercury oxide prepared ? What happens when it is heated ?

9. How do we usually test whether a given gas is oxygen ?

10. What is meant by *oxidation ?* State all cases of oxidation that have so far taken place in our experiments.

CHAPTER XI

VENTILATION—CAUSE OF WINDS

Experiment 1.—Take two bottles or jars, one wide-mouthed, the other with a very narrow opening, and place a small bit of burning candle into each.

The candle in the bottle with a narrow neck will soon go out; the other will continue to burn. Our previous experiments enable us to explain this. First, we have reason to believe that a candle in burning takes away oxygen from the surrounding air; from this it follows that the burning in a closed space must end as soon as all the oxygen present is removed. In the second place, we know that the air around a burning candle must become hot. Hence an uprush of hot air must take place in both jars. Now the narrow neck of the one bottle is filled with a jet of hot air rushing outwards, which acts almost like a stopper and prevents fresh and cold air from outside from getting in; hence when the oxygen present becomes insufficient for supporting burning, the candle goes out. In other words, the chemical action between the oxygen and the substance of the candle is then brought to an end, because there is no longer any oxygen there. In the wide jar, on the contrary, cold fresh air from outside can rush in by the side of the upward current of hot air; new oxygen is thus brought in to supply the place of that which was consumed, and the burning continues.

Experiment 2.—Fit a cork to the wide jar with two holes in which tubes can be moved up and down. Place at the bottom of the jar a burning candle (Fig. 11).

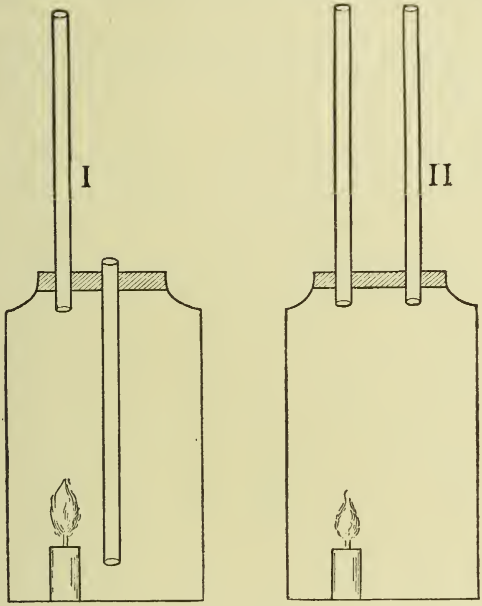

FIG. 11.

In the position (I) of the tubes the candle will continue to burn. As soon as the lower tube is raised to position (II) the candle will go out. In this position we have a bottle with two narrow openings instead of one, and this state of matters is not much more favourable to the supply of fresh air from outside than one narrow opening. But if the second tube is lowered, the hot and lighter air can conveniently escape by the upper tube alone, while fresh, cold, and heavier air comes in by the lower. That this is so may easily be shown by holding a smouldering piece of paper above and pretty close to the top of either tube; the smoke moves downwards at the mouth of the tube which is lower inside, and upwards at that of the tube which is higher inside.

Currents of this kind, in which a hot and lighter gas or liquid rises, while a cold and heavier one flows in below to supply its place, are called *convection-currents.*

Experiment 3.—Fix a burning candle to a piece of cork and float it in some water in a flat dish. Cover it with a bell-jar.

We know already what will happen: the candle will soon cease burning. But knowing also that this happens in consequence of the removal of the oxygen, we expect the water to rise within the bell-jar to take the place of the oxygen, as when the iron acted on air in Experiment 1 of the last chapter. The water, however, does not rise. The first explanation that we might suggest is that in this case the gas which remains behind is heated by the candle, and expanding fills more space than before, so that it prevents the water from rising; but we shall not see the water rise even after waiting till the jar and its contents are quite cold again. Now we have seen that when the iron removed the oxygen, chemical union of the two produced a new body, iron oxide or rust, which was a reddish powder—that is a solid body—and which took up very little more space than the iron in it. But we may suppose that though the oxygen was removed by the burning candle and entered into chemical union with the substance of the candle, or with some elements making up that substance, so as to form one or more new bodies, yet these compounds were not solid bodies, but gases. In that case there would be left in the bell-jar not only four-fifths of its bulk of nitrogen, but an additional bulk of the new gas or gases formed. There would then be no rise of water possible, the gases inside probably exerting indeed a greater pressure together upon the surface of the water than the air outside. We shall very soon see that our conclusion is quite correct, and that the products resulting from the combustion of a candle are gaseous bodies.

Experiment 4.—Open the door of a room which leads into a cooler room or passage an inch or two, and hold a burning candle in the opening, first near the top, then near the floor.

The flame when held above is blown from the room; when placed below it is blown into it. When held about midway between top and bottom it is blown neither way and burns pretty steadily. There is thus a current of air flowing out of the room in the upper portion, while a current of air flows inwards in the lower part. Nor can we be in doubt about the cause. In a room where a fire is kindled or lights are burning, or human beings are living, or in which there are any bodies warmer than their surroundings, warm air is continually rising upwards. The draught in the chimneys of fireplaces and lamps is similarly a consequence of the fact of hot air being lighter than cold air. If communication is allowed between the room and the air outside, which is colder, this colder and heavier air flows inwards along the floor, while the hotter air escapes upwards, as is the case in a chimney or any suitable opening for ventilation left in the upper part of the room. If there is no chance of escape for the hot air it rises and is gradually cooled by coming into contact with walls and windows, from which it flows downwards again. In this latter case no complete ventilation can exist, for it is the same air that circulates in the room. But we shall soon see that a constant renewal of the air around us is a condition of healthy human life; hence for complete ventilation we require an exit for the warm and impure air high up in a room, together with a free inlet near the floor. When the doors and windows of a room are made to fit so closely as to prevent a free flow of air inwards, and a fire is lighted, the air required for its maintenance comes in through the chimney instead of from the doors and windows. The consequence will be that smoke is blown into the room.

By a circulation similar to that by which the air in a

room is renewed, the whole atmosphere of the earth is kept in continual motion. If an extent of country is hotter than the neighbouring regions, the air in contact with it becomes heated, it expands, and rises upwards towards the higher regions of the atmosphere, while in consequence of its greater weight the colder surrounding air rushes in to supply its place. Thus the atmosphere becomes disturbed to a greater or less degree, and to these disturbances the name of *winds* is given. In the simple case here assumed two distinct winds will be produced—an upper one setting *from* the heated region, and a lower one setting *towards* it.

QUESTIONS ON CHAPTER XI

1. Explain why a candle will burn in a wide-mouthed jar but not in a bottle with a narrow neck.

2. Show how we may produce currents in a jar with *two* narrow openings, which will allow a candle to burn in it.

3. What is meant by convection-currents? Describe with the help of a sketch how the convection-current moves in the jar used in Experiment 2, position (I).

4. Explain why we expect the water to rise in a bell-jar in which a candle burns over water.

5. Why does the water not rise in that experiment?

6. How can we show that in a room there are two opposite currents of air moving?

7. Draw a sketch of a room showing how you would ventilate it. Show by means of arrows how the currents of air move in your system of ventilation.

8. Explain the cause of winds. Suppose it were much hotter in England than Scotland, in what direction would the wind probably blow in England? How would the clouds appear to move in that case?

CHAPTER XII

LIMESTONE, LIME, LIMEWATER, GYPSUM

Experiment 1.—Place a few pieces of marble, or limestone, into a bottle with a moderately wide mouth, and pour a small quantity of strong vinegar upon them.

Lively action commences between the marble and the acid liquid; bubbles of gas are disengaged and rise to the surface. A gas is thus set free which will collect above the liquid. Now if this gas were air, a candle would burn in it; again, if it were lighter than air it would at once rise upwards, and a candle would still burn in the bottle above the liquid.

Experiment 2.—Let down a burning candle into the bottle, after waiting a few minutes.

The candle will go out at once. This proves that we have before us a gas which is heavier than air, and which does not support the burning of a candle. It cannot well be nitrogen, because nitrogen, constituting four-fifths of the air, cannot be heavier than air unless oxygen is very light; but in fact oxygen is somewhat the heavier of the two, and nitrogen is slightly lighter than air. It is indeed a new gas with which we are now becoming acquainted, and it is called *carbonic acid.*

In ordinary chalk, limestone, and marble this gas is chemically combined with a substance called *quicklime.*

It is easily seen that carbonic acid is a different substance from either chalk, limestone, or marble, but we must prepare quicklime from either chalk or limestone to see that they are really different substances, for they are somewhat similar in appearance. Quicklime is a very useful substance, especially for building purposes, where it is employed in the preparation of mortar. It is prepared on a large scale by burning limestone together with coal in so-called limekilns; in this way the chemical union between the quicklime and carbonic acid is broken up by heat, the carbonic acid escaping while the quicklime is left behind.

We can only experiment on a very small scale.

Experiment 3.—Heat a small piece of chalk on charcoal before the blowpipe for several minutes.

Quicklime is somewhat soluble in water, while chalk is not. Hence, if a small quantity of chalk be thrown into a pint bottle full of water, which is well shaken, the granules of chalk will be seen to settle at the bottom; on tasting the water it will be found to have the taste of ordinary water. If the experiment is repeated with a fresh portion of water, and the quicklime produced by our experiment, it will be seen that quicklime is soluble in water; not being very soluble, some of it will remain visible, but that some has dissolved is seen from the fact that the water will have acquired a peculiar taste, to which the name *alkaline* has been given.

Experiment 4.—Put a lump of quicklime on a tin plate and sprinkle some water over it.

In a little time the piece of quicklime will crack in several places, and become very hot. Steam is produced in consequence of the hot lime evaporating some of the water poured upon it, while some of the water combines chemically with the quicklime and forms a compound

which appears as a fine white powder, called *slaked lime*, which consists of quicklime and water in chemical union.

The experiment also shows that chemical union is a source of heat; a fact which is abundantly proved by the burning of coal in a fire, or by the flame of a candle, where, as we have already learnt, the substances of the fuel or candle combine with the oxygen of the air.

Experiment 5.—Put a little slaked lime in a bottle containing water and shake it for a few minutes.

A portion will dissolve. Allow the remainder to subside, and pour the clear solution into a fresh clean bottle. Close the bottle with a well-fitting stopper, and label it "limewater." It will be required for some experiments of the next chapter.

Experiment 6.—Heat a little gypsum in a small test-tube.

Observe that the mineral loses its shining appearance, and that at the same time drops of water appear near the top of the test-tube. If the gypsum is heated on charcoal the water is driven off more conveniently, and a white powder, the so-called "plaster of Paris," is left. This, on being mixed with water to form a paste, again unites with it, and the mass becomes solid and compact; this is called "hardening."

Here we have an instance of water having entered into chemical union with another body, and being removed from it by the application of heat. But gypsum differs from slaked lime in this respect, that the water cannot be removed from dry slaked lime by mere heating. The gypsum is originally in the form of a crystal, but it loses water and its crystalline shape together upon being heated. Water thus combined with a substance is called *water of crystallisation.*

Experiment 7.—Heat a few pieces of marble in a small test-tube.

No water makes its appearance, nor does the marble seem to undergo any change. There is no water of crystallisation in marble, but if we heat a piece of marble very strongly in a furnace, and weigh the piece before and after heating, we shall find that it has lost in weight. This loss is due to the carbonic acid which has escaped by the heating. The marble has thereby been converted into quicklime.

QUESTIONS ON CHAPTER XII

1. What happens when vinegar or an acid liquid is poured upon marble or chalk ?

2. By what experiments and observations do we show that it is not air which fills the bottle immediately afterwards ?

3. Describe the effect of heat (1) upon chalk ; (2) upon gypsum ; (3) upon marble.

4. By what experiments would you show that a given powder is chalk ?

5. Describe the differences existing between chalk, quicklime, and slaked lime.

6. Give examples of the production of heat by chemical union ?

7. What is meant by *water of crystallisation ?* Mention some bodies which usually appear in the form of crystals ?

8. How is plaster of Paris made ? What happens when it hardens ?

CHAPTER XIII

CARBONIC ACID AND LIMEWATER—CARBONIC ACID IN AIR

Experiment 1.—Set up the apparatus shown in Fig. 12, and pour acid through the funnel-tube into the bottle A, which contains some pieces of marble.

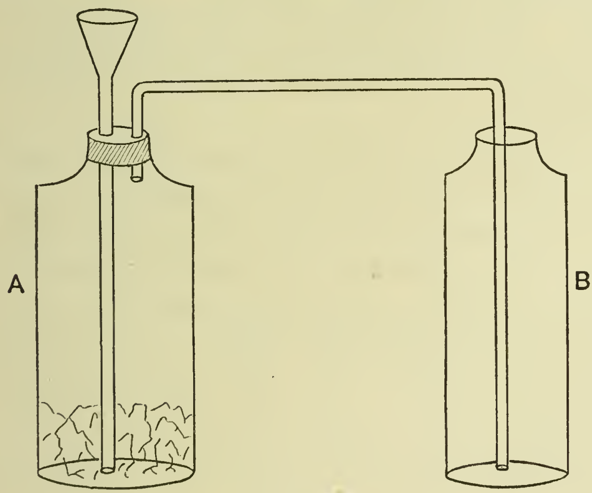

Fig. 12.

Bubbles will appear at once, and the gas will collect in the jar B, pushing the air out at the top. This mode of collecting a gas which is heavier than air is called "collection by downward displacement." After a little while lift the bottle A up so as to be able to remove B conveniently, and place another jar in its place to be filled with the gas.

In this manner a few jars may be filled with it, and by covering their mouths with glass plates, slightly greased, the jars with gas may be kept for further experiments.

Experiment 2.—Fix a burning candle at the bottom of a jar full of air, and pour a jar of carbonic acid upon the candle.

The candle will go out. Hence carbonic acid gas must have fallen to the bottom of the jar, and displaced the air upwards. This is a still more satisfactory proof that carbonic acid is heavier than air, than that in the last chapter. The gas, though itself invisible, falls through the air and produces a visible effect.

Experiment 3.—Pour a small quantity of water into a jar containing carbonic acid gas, holding it in your left hand. Press the palm of your right hand firmly upon the mouth of the jar and shake it vigorously for a few minutes.

Observe that your hand is soon pressed into the jar from outside without any effort on your part: this can only be due to the pressure of the air. Hence we may conclude that some of the gas inside is no longer capable of exerting an opposing pressure. Some of it must have gone into the water, that is, must have been dissolved by it, for it could not escape in any other way. If we taste the water we shall find that its taste is somewhat different from that of ordinary water; it is slightly prickly to the tongue, like soda-water which has been standing in a tumbler for some time.

Experiment 4.—Pour the water used in the last experiment from the jar into a small beaker, and into another beaker of the same size an equal quantity of ordinary water. Heat both gently.

Observe both beakers carefully as the liquids become

warmer and warmer. Small bubbles of gas will soon rise in both from the bottom and sides; at first a few, then more. But there will soon be many more rising from the water which contains the carbonic acid; the ordinary water has, as we see, some gas dissolved in it also, but it is chiefly air. When we reach the point at which both liquids boil, we shall see no great increase in the number of bubbles that arise from the ordinary water; here and there a bubble rises up with the steam; but the carbonic acid is given up by the water which contains it most rapidly.

This experiment proves, in the first instance, that water is capable of dissolving gases like air and carbonic acid; in the second place, that carbonic acid is more soluble in water than air; and in the third place, that when a solution of a gas in water is heated the gas escapes, and hence that hot water cannot dissolve so much gas as cold water. It is otherwise, as we have seen, with solids, of which, as a rule, hot water can dissolve more than cold water.

Knowing that carbonic acid and lime when combined form chalk, limestone, and marble, and having left from Experiment 5, Chapter XII, a solution of lime in water, we may try to form chalk by passing into some limewater the carbonic acid generated in our apparatus.

Experiment 5.—Pour a little limewater into the jar B, connect it with A as in Fig. 12, and pour some acid down the funnel-tube.

As the gas produced passes through the limewater the liquid becomes turbid and milky in appearance, and a thick white sediment gradually forms, when after a few minutes the jar B is removed. To understand what has happened we must consider that lime is soluble in water, but lime carbonate, or chalk, is not soluble. Hence when the gas combines with the lime, the chalk formed by their union becomes visible as a white powder, because it is insoluble. Such a white sediment of a body thrown down

by chemical union is frequently called a *precipitate* (from the Latin *prae*, before; and *caput*, head, a thing thrown down headlong). It often serves to show what is really going on in a solution, and so to indicate the presence of certain substances in it. If we pour a little acid into the jar which contains our precipitate, it will be redissolved, and the carbonic acid will be driven out again in the form of bubbles.

Limewater is called a *test* for carbonic acid, because the presence of carbonic acid, whether alone or mixed with other gases, may be detected by the production of a white precipitate in limewater.

Experiment 6.—Pour a little limewater into a small china dish and expose it to the air.

The water soon becomes turbid at the surface and covered with a film which gradually grows thicker and sinks to the bottom. This proves the presence of carbonic acid in the air. Nor should we wonder at its presence, considering that carbonic acid must be produced whenever carbon, that is charcoal, or any substance which contains it, for instance wood, coal, a candle, etc., burns in air.

Experiment 7.—Prepare a jar with tubes as in Fig. 13, and pour some limewater into it. First *suck* at the end *a* for half a minute; then *blow* for a short time into the jar at the end *b*.

By sucking at *a* we shall draw air from outside through the limewater. No very perceptible effect is produced, because the quantity of carbonic acid gas mixed with air is very small, 10,000 parts of air containing only 4 parts of carbonic acid gas. But if we blow through *b*, it is air from our lungs which we send through the limewater, and the effect is striking. The air from our lungs contains a very large admixture of carbonic acid gas, as is shown by the precipitate produced in the limewater. Nor is the

explanation difficult. The air we breathe brings oxygen to our lungs. Here it acts on our blood, which contains carbon, and thus forms carbonic acid by chemical union,

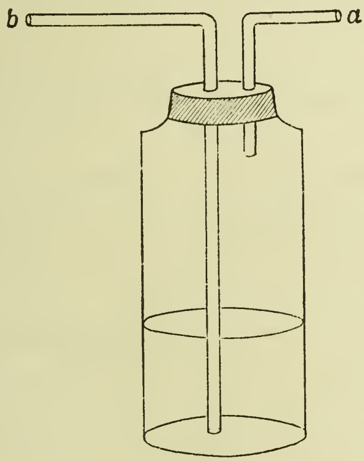

FIG. 13.

and this chemical union again is the cause of our body being so much warmer than such of the objects surrounding us as are without life.

QUESTIONS ON CHAPTER XIII

1. Sketch and describe an apparatus for making carbonic acid gas, and state how several bottles of the gas may be collected and preserved.

2. Describe and explain an experiment which satisfactorily proves that carbonic acid gas is heavier than air.

3. How would you make water first dissolve some carbonic acid gas, and then give it up again ?

4. When a glass of water is left standing in a warm room for some time, a number of small bubbles are seen inside the glass and close to it. What are they and how do they get there ?

5. What difference is observed between solutions of solids and gases when heat is applied ?

6. What is going on when carbonic acid gas is passed through limewater ? By what experiments could you prove your answer ?

7. How is it proved that air always contains some carbonic acid gas ? How much is usually there, and whence does it get into the air ?

8. What difference is there between the air which we take into our lungs and the air we breathe out ? How could you show the difference by experiment ?

9. Whence does the carbonic acid gas come which is given out by our lungs ?

10. Why is it that our body is warmer than objects around us ?

CHAPTER XIV

CARBONATE OF LIME IN WATER—HARD AND SOFT WATER

Experiment 1.—Take half a tumblerful of water from the tap, and add some limewater.

Observe that a white precipitate is produced. Hence there must be carbonic acid gas dissolved in the water. How did it get into it? Let us consider from whence it is that we ultimately derive all our water. This particular glass of water comes from a river, or a well. But the river is nothing but rain water collected into the bed of the river from a large extent of sloping country; the well water is nothing but rain water which has sunk into the soil simply by its own weight, and has collected in a hole dug for the purpose. Now rain is water which has passed through a very thick layer of air; air contains a small quantity of carbonic acid; carbonic acid is soluble in water; no wonder then that our water contains carbonic acid gas dissolved.

Experiment 2.—Boil some water from the tap in a thin glass flask on a tripod, over a spirit flame or gas-burner.

Several changes which now go on will call for our attention. In the first instance, before the water boils small bubbles of air make their appearance and rise to the surface, where they burst. Next, as we come nearer to

the boiling point, some of the water at the bottom will become steam by contact with the hot glass, which is nearest to the flame; bubbles of steam will rise, but not up to the surface at first, because the water above them is still too cold; hence as they rise they will become water again before reaching the surface. This is precisely what distinguishes the air-bubbles which we saw rising to the surface from the beginning from the bubbles of steam which announce the approach of boiling. Frequently the collapsing of these steam bubbles is accompanied by a kind of *singing* noise. At last the bubbles rise up to the surface, and now the whole is boiling. Portion after portion of the water is now becoming water-gas or steam, by the action of heat, and the steam rushes out at the mouth of the bottle to mix with the surrounding air. But observe how clear the space inside the bottle is, while from the mouth of the bottle there rises a kind of fog or cloud. Steam, as it appears close to the boiling water inside the hot bottle, is a colourless invisible gas; as soon as it meets with the colder air outside a portion of it becomes water again, or is "condensed," as it is called.

Up to this point the water itself remains as clear as when we put it into the bottle; but as we go on boiling it we see it becomes turbid and somewhat thick. There will also be white grains of solid matter left on the sides of the bottle as the water diminishes in bulk. We thus not only see that ordinary water contains solid matter in solution, but by continuing the boiling till all the water is evaporated, and pouring a little acid on the solid matter left, we can easily satisfy ourselves that this solid matter contains carbonic acid gas. Indeed it consists chiefly of carbonate of lime. Now carbonate of lime is not soluble in pure water, but as we have proved that our water among other things contained carbonic acid gas in solution, the solubility of the carbonate of lime may possibly be due to the presence of carbonic acid gas in the water. We

may prove the correctness of our conjecture by an experiment.

Experiment 3.—Set up the apparatus of Fig. 12, prepare carbonic acid gas, and let the gas bubble through some limewater in the bottle B.

We know already what will happen first: the lime and carbonic acid combine and form carbonate of lime, which is insoluble in water, hence a white precipitate makes its appearance. But as we allow more carbonic acid to pass through water, the water dissolves the gas, and a new effect is rendered visible; the water becomes clearer and clearer, in other words, the precipitate of carbonate of lime is dissolved by water which is charged with carbonic acid gas.

But how is it that the carbonate of lime, dissolved in ordinary water which has taken up some carbonic acid gas, is rendered visible when the water is boiled? This is easily understood when we recollect that hot water cannot hold so much of any gas in solution as cold water.

Experiment 4.—Boil the liquid from the bottle B in a beaker.

The hotter the liquid gets the more gas is expelled, and the more turbid the water becomes from the separation of the carbonate of lime, which is no longer soluble for want of carbonic acid. Finally, when the liquid boils, we may remove it from the lamp, and let it stand quietly, when a dense layer of carbonate of lime will form a sediment at the bottom of the beaker.

The preceding experiments throw light upon matters of great practical importance. In the first instance they explain how rain water charged with carbonic acid gas flowing over soils and rocks which contain limestone, that is carbonate of lime, dissolves some of it, and thus though perfectly clear to all appearance, contains carbonate of lime. Now such water is no longer pure water; moreover

while pure water will form a lather with soap, and in consequence cleanse what is washed with it, water containing carbonate of lime has a peculiar action upon soap, forming a curd, but no lather, and prevents the soap from acting properly. Hence such water is called *hard water*, while water free from such matter is called *soft water*.

But the experiments also show that by removing the carbonic acid gas from water we may precipitate the carbonate of lime, and thus render hard water soft. This can be done in two ways, as we can learn from our experiments: (1) by boiling the water; (2) by adding limewater, that is lime, for this will combine with the carbonic acid gas present in the water, and thus render the water incapable of holding any carbonate of lime at all in solution. Either upon boiling the water or upon adding lime the carbonate of lime in solution ceases to be soluble, and falls to the bottom, leaving soft water above it.

QUESTIONS ON CHAPTER XIV

1. How is it proved and explained that ordinary water contains carbonic acid gas in solution ?

2. Describe accurately and in their proper order the occurrences which may be observed when water is gradually heated and allowed to boil for some time.

3. What is the solid matter which is seen in the boiling water and on the walls of the flask ? How could it be collected ? How could it be shown to contain carbonic acid gas ? How did it get into the water ?

4. How is it proved that steam is invisible ? What do we see at the spout of a kettle in which water is boiling ?

5. What do we generally see at the bottom of such a kettle when it has been long in use ? How is the presence of that substance in the kettle explained ?

6. What is the difference between hard and soft water ?

7. By what artificial means could soft water be made hard ?

8. In what two different ways could hard water be made soft ?

CHAPTER XV

DISTILLATION

Experiment 1.—Place a few drops of ordinary well-water upon a small glass plate, or on a watch-glass, and warm it gently until the water has evaporated.

On looking at the glass a small quantity of dry solid matter will be seen to have been left behind. We know already, from previous experiments, that ordinary water contains solid matter in solution. This solid substance, it appears, could always be obtained by simply boiling away all the water in which it was dissolved. But could the whole of it be separated in this way from the water?

Experiment 2.—Boil a little water in a test-tube. Close to the mouth of it hold a very clean glass plate until drops of water appear upon it. Evaporate these drops as before.

Now no solid matter is left behind. The water upon the glass plate is condensed steam, and no solid matter previously dissolved in the water is taken up in the steam; consequently none is found after the water deposited on the plate is driven off. Condensed steam is perfectly pure water. We may confirm this fact, which is of much practical importance, by a few additional experiments.

Experiment 3.—Dissolve some salt in a little water,

taste the solution and then boil it in a test-tube. Condense some of the steam upon a glass plate as before. Taste it.

Experiment 4.—Colour some water with any colouring matter, such as magenta or indigo, and proceed as before. Hold the glass plate against the light.

The drops of water received on the glass plate in the first experiment have no taste of salt; those received in the second experiment are perfectly colourless.

From these experiments we learn—(1) that when a solid body is dissolved in water we may obtain the *whole* of it again by boiling the solution until the water is completely evaporated; (2) that we may also obtain the whole of the water, and in a perfectly pure state, by arranging our experiment in a suitable manner so as to catch all the steam produced by boiling.

The steam into which the boiling water is converted is first as hot as the water. The air outside and the glass plate are colder; we may therefore conclude that the condition necessary to the reconversion of steam into water is that it should be cooled, and this is not only proved by these experiments, but may in addition be confirmed by holding a very hot glass plate, or better still a very hot plate of tinned iron, over the mouth of the test-tube; no condensed water will be seen upon it until the plate has become much cooler.

The process of boiling water or any other liquid, condensing the vapour and collecting the liquid by suitable means, is called distillation. It is not only employed for separating liquids from impurities which arise from admixture of solids in solution, but it may also be used for separating two or more liquids from each other. If of two liquids which are mixed together one boils sooner than the other, when the mixture is heated it will be converted either partially or wholly into vapour before the other

liquid boils; we may then condense this vapour, and thus obtain the former liquid separately from the latter. This process is called *fractional* distillation.

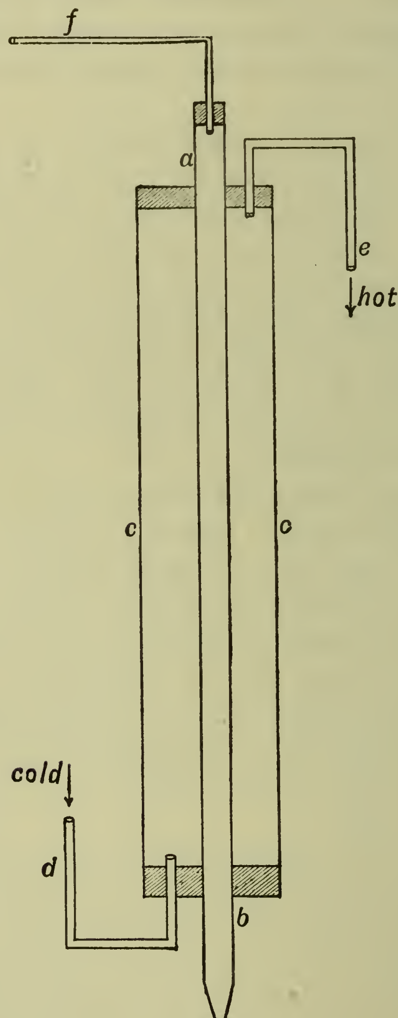

Fig. 14.

The apparatus in which the vapour is condensed, the *condenser*, usually consists of a tube which is surrounded by

a wider vessel filled with cold water. As this water soon becomes heated by contact with the tube which contains the hot steam, provision must be made for a frequent renewal of the water in the condenser. Fig. 14 shows a simple apparatus for this operation, which can be easily put together. A wide tube of glass, *cc*, is closed at both ends by corks. A tube *ab*, having a somewhat narrower opening below than that above passes through both corks of the wider tube; its upper end is closed so as to be airtight by a cork perforated for a narrow tube *f*, which leads to a vessel in which the steam is generated. The lower end is loosely placed into the neck of any vessel convenient for receiving the condensed liquid. Cold water passes into *cc* by means of a narrow tube *d*, which is bent twice at right angles, one limb being connected with the top of some capacious vessel containing cold water, the other limb ending close to the bottom of *cc*. The heated water flows off at the top of *cc*, through a narrow tube *e*, one limb of which is fixed into the upper cork.

QUESTIONS ON CHAPTER XV

1. What happens when a few drops of ordinary water are placed on a piece of glass and heated?

2. Why do you expect to find some solid matter left on the plate in this experiment?

3. Describe the experiments made to show that when steam is allowed to be condensed on a glass plate, no solid matter is contained in the water formed.

4. What conclusions can we draw from these experiments?

5. Describe the process known as *distillation*.

6. What property of liquids enables us to separate one liquid from another by distillation?

7. Describe and draw a diagram of an apparatus for distillation, explaining the use of every part of it.

8. Describe some practical applications of distillation.

9. How would you separate spirits of wine from water by fractional distillation?

CHAPTER XVI

ACTION BETWEEN WATER AND SOME METALS—HYDROGEN

Experiment 1.—Ram a piece of sodium tightly into a short piece of lead-tubing closed at one end, and place it into the water under a small jar, or test-tube, inverted as in Fig. 6.

Bubbles of gas will rise from the open end of the lead tube into the inverted jar. Some action is going on between the water and the sodium, which continues until the metal has disappeared. The action cannot be a simple solution of the sodium in water, as in the case of a piece of sugar, because a new body, the gas in the jar, makes its appearance at the same time. This gas is not likely to be air, for so long as the mouth of the jar is under the surface of the water no air can enter from outside.

Experiment 2.—Lift the jar when full of gas, or nearly so, out of the water, keeping its mouth downwards, and pass the flame of a rather long taper up into the gas.

The gas takes fire at the mouth of the jar or tube; and burns there with a pale flame, but the taper inside is extinguished; on bringing it down to the mouth of the jar again it can be rekindled at the burning gas and taken out burning.

These experiments throw much light upon the nature of

the gas we have obtained by the action of the metal sodium on water. The gas has no colour, it burns, and it extinguishes a burning taper. Further, it is not heavier than air, for if it were it would not remain in a jar held mouth downwards. Indeed it may be shown to be much lighter than air by filling a jar with it and bringing its mouth covered with a glass plate under that of another jar filled with air and held above it, mouth downwards. On withdrawing the plate and applying a lighted taper to the mouth of the upper jar the gas in it burns with a slight explosion. The air has sunk down into the lower jar, while the gas has passed into the upper. The experiment proves the gas to be so much lighter than air that it may be poured *up* through it.

The name of the gas thus obtained is *hydrogen* (from the Greek words *hydor*, water ; and *gennao*, to produce).

Experiment 3.—Stick a little piece of sodium upon a stiff wire, and cut it through the middle with a penknife.

Notice at once the bright silvery surface of the freshly-cut metal, and observe how soon it becomes tarnished. From previous experiments on the action between air and various metals, we are led to think it very probable that the sodium becomes tarnished because it takes oxygen from the air, and that it forms by this combination a new body, sodium oxide. Again, it is a common experience that iron when kept for some time under water, or when drops of water are left upon it to dry, becomes rusty more quickly than when exposed to ordinary air, and we know that rust is a compound of iron and oxygen. We are thus led to conjecture that the action of water upon sodium may possibly be also to convert it into an oxide of sodium, and to conclude that, if this is the case, water is a compound of oxygen and the new gas which we have made, and which we call hydrogen, and that the sodium when

placed in the water takes up the oxygen and sets free the hydrogen.

Experiment 4.—Boil some water in a flask and pass the steam over red-hot iron, as shown in Fig. 15.

At first air will pass over into the vessel W containing water, and then steam; the jar J should not be placed over the end of the tube until all the air is swept out. When this is the case a gas will rise in J and displace the water; as soon as the jar is full it may be simply raised, mouth downwards, and the flame of a taper applied to the gas, which will burn as in the preceding experiments. The iron in the tube T has become partly converted into oxide of iron, and has broken up the compound body which we call water, retaining the oxygen and setting free the hydrogen.

Very few metals are, like sodium, capable of breaking up water in the way shown in Experiment 2; iron must be assisted by heating it, and also by presenting the water to the metal in the form of steam. But neither by the action of sodium nor that of iron, as presented in Experiments 2 and 4, can large quantities of hydrogen be obtained. The gas may, however, be made on a larger scale by acting upon zinc with a mixture of water and sulphuric acid (oil of vitriol).

Experiment 5.—Drop a few pieces of zinc into a test-tube half full of water. Add a little sulphuric acid.

Observe that no action occurs until the acid is added. Bubbles of gas will then begin to rise, which consist of hydrogen. Prove this by allowing the action to proceed for a few minutes and then applying a light to the mouth of the test-tube.

Experiment 6.—Heat a little copper-foil in a bright smokeless flame.

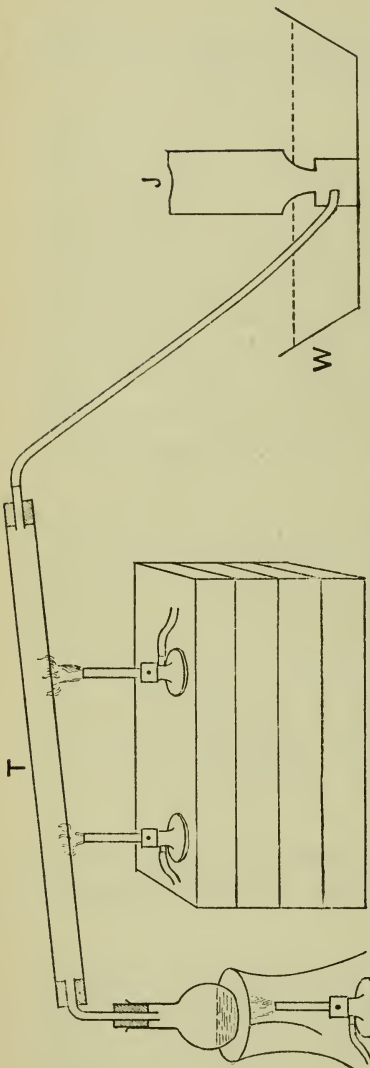

Fig. 15.

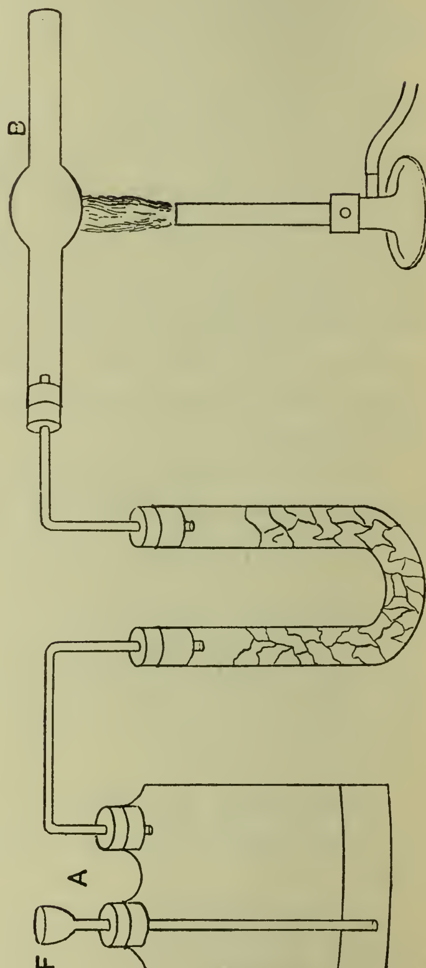

Fig. 16.

The copper, as we know from previous experiments, becomes oxidised. The oxide of copper is a black powder, which may be scraped off. Heat the copper again, and by repeatedly heating the copper and scraping off the black crust formed, collect a small quantity of the oxide. Place it into the wide part of the bulb-tube B, Fig. 16, and set up an apparatus as in the figure. The bottle A contains zinc clippings and some water. When a little sulphuric acid is poured upon this through the funnel-tube F, hydrogen will be produced. It will be mixed with a little vapour of water, which for the purpose of our experiment must be removed. This is done by passing it through a so-called U-tube filled with bits of a substance called calcium chloride, which has the property of absorbing the vapour of water, and therefore allows the hydrogen in a dry state to enter the tube B. Let the action go on for ten minutes, then light the burner under the bulb containing the copper oxide, and proceed to the experiment itself.

Experiment 7.—Pass dry hydrogen over heated copper oxide.

Observe that steam issues from the free end of the tube B as soon as the copper oxide is heated, but not before. Further, that the black powder turns red and becomes copper again, having clearly given up its oxygen to the hydrogen which passed over it, and that water is formed by their union. If a little of the steam is caught upon a small watch-glass, it can easily be proved to be pure water.

We have thus proved that water is formed by the union of two bodies very different from each other, and from water itself, in many of their properties. We have also seen that we may prove this either by breaking up water or by making the two substances of which it consists enter into union. The hydrogen in removing the oxygen from the metal with which it was united, as in the last experiment, is said to *reduce* the oxide; the action itself is a

reduction, and is clearly the very opposite of an *oxidation*; that is, the kind of action of which we have seen instances in former experiments, and again in Experiment 6, when copper was heated in air. Both are chemical actions; and two very important classes of chemical action, which the experiments of this chapter are presenting in a very striking way, are the breaking up by some means of a body called a compound, and possessing certain properties, into other simple bodies having different properties; and the uniting such simple bodies differing from one another in most or all respects to produce a new body differing altogether from the simpler bodies of which it is made up.

QUESTIONS ON CHAPTER XVI

1. What is observed when sodium is placed under water? What is the name of the gas produced?

2. State the principal properties of the gas, and how they are proved by our experiments.

3. How do our experiments prove that water is a compound of oxygen and hydrogen?

4. Describe fully what happens when steam is passed over heated iron. Sketch and describe the apparatus used.

5. Describe three different ways of preparing hydrogen. How is it usually prepared on a large scale?

6. Sketch and describe the apparatus used for passing hydrogen over copper oxide.

7. What is meant by *reduction?* How does it differ from *oxidation?* Give examples of either.

8. Give examples of chemical actions, and explain why you call them chemical actions.

9. Compare the properties of steam, hydrogen, and nitrogen; pointing out those properties in which they agree, and those in which they differ.

CHAPTER XVII

THE BURNING OF A CANDLE—ACTION OF ANIMALS AND PLANTS UPON AIR

When we wish to light a candle we apply a burning match to the wick—that is, we heat the wick. As the candle burns it seems to disappear; when it has burnt out nothing seems to be left of its substance but a little ash. What is going on when the candle burns? What becomes of it when it has burnt away? In order to answer these questions we may first of all look back upon the results of Experiments 1 and 2 in Chapter XI. We learnt from them that a candle burning within a vessel with a narrow neck will soon go out, while it will continue to burn if a constant supply of fresh air can be maintained around the flame. But we have also learnt since that there are gases which are unable to support combustion, and the question arises, whether some of these gases—for example, carbonic acid gas—may not be formed while the candle burns; if so, this would account not only for the candle going out in a closed space, but also for its apparent gradual disappearance while continuing to burn.

Experiment 1.—Attach a piece of burning taper to a long wire and let it stand in a bottle with a narrow neck (Fig. 17).

The candle will go out very soon, and being careful to take the taper out directly it is extinguished, and without

allowing it to smoulder, we put a stopper into the mouth of the bottle. An invisible gas will fill it, and in order to see whether it is carbonic acid gas, we pour some limewater into the bottle and shake it up and down a few times. The milkiness of the liquid convinces us that the bottle contained carbonic acid after the candle ceased burning, for it

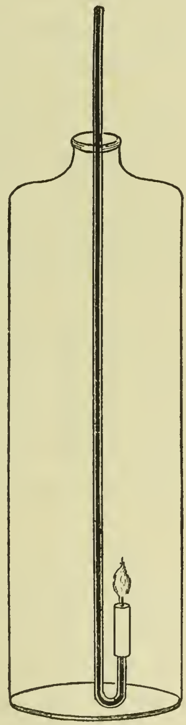

FIG. 17.

was not there before, as can easily be proved; if previous to the experiment some limewater is poured into the bottle no milkiness is perceptible.

We know from former experiments that many substances, when strongly heated in air, enter into chemical union with the oxygen contained in the air, and form new bodies called oxides; thus tin, when heated, forms tin

oxide; copper forms copper oxide, and so on. Now carbonic acid, as it is usually called, is nothing else than a body formed by the chemical union of carbon and oxygen. In our experiment, as a little consideration will show, the oxygen is supplied by the air round the burning candle, and the carbon by the tallow, or wax, or stearine, of which the candle is composed, and by the wick. But as the candle is clearly not pure carbon or charcoal, the question arises, is anything else formed when a candle burns?

Experiment 2.—Hold a clean dry beaker mouth downwards over a burning candle for a few seconds.

The interior of the glass will very soon appear dim, because moisture is deposited upon the sides. We may easily convince ourselves that this is water formed while the candle is burning. Since water is a chemical compound of oxygen and hydrogen, the experiment proves that, besides carbon, the substance of the candle contains hydrogen also, and this, in burning, enters into union with the surrounding oxygen, forming oxide of hydrogen, usually called steam in its gaseous form, or water when condensed to a liquid.

As we may readily prove by breathing upon a cold glass plate, steam as well as carbonic acid is given out by our own lungs in breathing, and we are thus led to see very clearly the similarity between the process of breathing in men and animals and the burning of a candle; and to understand that just as heat is produced by the union of the carbon and hydrogen in the wax or tallow of a candle with the oxygen of the air, so the heat of our own bodies is due to the same cause, some of the carbon and hydrogen contained in our blood being constantly carried to our lungs, combining there with oxygen taken in from the air outside, and being then thrown off as carbonic acid and steam, while the loss is restored by the substances which we eat and drink.

We cannot, therefore, wonder that carbonic acid is always present in the air; what is surprising is that this gas, which is unable to support combustion, and is therefore destructive of animal life, is not present in greater proportions; for animal respiration, as well as the combustion of coal and other fuel, is constantly going on, and larger and larger quantities of carbonic acid are thus mixed with the air. Some provision must therefore exist in nature to remove the carbonic acid from the air again, for it would otherwise finally accumulate so as to destroy all animal life.

Experiment 3.—Place a number of fresh leaves of any kind of plant into a jar, fill it with water saturated with carbonic acid, and invert it over a vessel containing water.

Observe that no change will take place in the feeble light of a room which is not exposed to the sun; but when the whole apparatus is placed for some hours into bright sunshine bubbles of gas will be seen to rise from the leaves and collect at the top of the jar. When a sufficient quantity has been collected cover the mouth of the jar with a ground-glass plate, as in former cases when experiments upon a contained gas were to be made, turn it mouth upwards and plunge into it a match with a glowing tip; the match is rekindled, thus proving the gas to be oxygen. As no hydrogen is produced at the same time, the gas can only have been produced by the action of the leaves present upon the carbonic acid; they separate the carbon and fix it for their growth within their own substance, while the oxygen escapes. It is thus that by the action of plants under the influence of the sun's rays the accumulation of carbonic acid in our atmosphere is prevented.

QUESTIONS ON CHAPTER XVII

1. Describe what change is ordinarily observed when a candle burns in air. Will the same change be observed when the burning candle is placed inside a bottle with a narrow neck?

2. How do we proceed to test if one or more new substances are formed when a candle burns?

3. How do we explain the presence of carbonic acid in the bottle in which a candle has been burning?

4. Why does a candle smoulder which has just ceased to burn?

5. Why is it desirable to remove the taper before it smoulders?

6. How can we prove that steam is produced when a candle burns? How is this explained?

7. State the points of similarity between the burning of a candle and our breathing.

8. Describe that action of plants which prevents the accumulation of carbonic acid in the air.

9. How can this action be proved by experiment?

10. How would you proceed to prove that each of the following substances contains carbon: *wax, tallow, oil, ordinary gas for lighting?*

CHAPTER XVIII

FURTHER ACTIONS BETWEEN SOLIDS AND LIQUIDS—CAPILLARITY

Experiment 1.—Place before you two similar glass vessels, and pour into one a little water, into the other a little mercury.

Observe carefully the surface of each liquid. Each surface becomes slightly curved where the liquid touches the sides of the vessel. In the case of the water the surface becomes curved upwards against the sides of the glass; it is *concave* (from the Latin *con*, together; and *cavus*, hollow); in the case of mercury the liquid is depressed against the sides of the solid, the surface is *convex* (from *con*, and *veho*, to carry—literally, carried together). Now we have already seen that glass dipped into water becomes moistened, but when dipped into mercury it is not wetted; in other words, the water will tend to spread itself out over the surface of the glass, but not the mercury. We are thus led to conclude that if a solid body partially immersed in a liquid is moistened by it, the liquid near the body will be raised; if, on the contrary, the solid is not moistened by the liquid, the liquid near it will be depressed below the level of that farther away.

Now what would happen in either case if the sides of each vessel could be brought nearer and nearer together so that it gradually takes the shape of a tube? In this case

those parts of the surfaces which are far from the sides would become smaller and smaller, and the action of the sides alone would be rendered more and more sensible.

Experiment 2.—Place several tubes of different internal bore side by side, first in water, then in mercury.

It will be seen that in water the liquid stands the higher the narrower the tube; in mercury the reverse is the case —that is, the liquid stands the lower the narrower the tube. Indeed it can easily be observed that if we select two tubes, one having half the internal diameter of the other, and place them both in water, the liquid will stand twice as high above the surface outside in the narrower tube as in the wider. When the tubes are placed in mercury, the liquid is also twice as much depressed in the narrower as in the wider bore; but as mercury is not transparent like water, it is somewhat difficult to observe the amount of depression in our tubes. The rise of liquids is particularly well seen in tubes of which the bore is extremely narrow, not larger than a hair (Latin, *capillus*); such tubes are called *capillary* tubes, and the action is called capillary action, or *capillarity*.

It is not necessary to dip glass tubes into liquids to observe this action; many bodies possess so many fine cavities in their substance that liquids will rise in them from the same cause.

Experiment 3.—Hold small portions of blotting-paper, sugar, sponge, and cotton wick into water, so as just to let it touch the surface in each case.

The liquid will rise more or less above the surface in the vessel in all these substances. It is from the same cause that oil rises in a wick, and water in wood. The action is therefore of much practical importance.

Experiment 4.—Rub a few drops of oil upon a clean board, and also upon a sheet of note-paper. Cover the

oiled part in each case with a thin layer of wet clay and allow it to stand for some time till dry.

The clay dries because the water contained between its particles evaporates. Hence cavities are left behind which absorb the oil by capillary action. When the clay is removed the oil spots are no longer visible. In this case the absorption of the oil by capillary action is helped by the pressure of the air, for the cavities contain no air when the water evaporates, and the pressure of the air all round drives the oil up into the empty spaces. This may easily be proved by repeating the experiment with dry clay, which may be powdered and spread over the oil spots; these will disappear very gradually, neither so rapidly nor so completely as when wet clay is used.

Experiment 5.—Form a few balls of moist clay. Dry one quickly with the help of heat from a burner, another slowly in the air of a room.

In the first ball cracks will appear when dry, in the second none, or at most only traces of them. The water in the first case evaporates so quickly that the particles of clay have no time to arrange themselves as uniformly near to one another as they were before. For this reason a clay soil shows cracks and fissures in dry weather which has succeeded rain. When clay which has been slowly dried in the air is strongly heated in a suitable furnace, the mass becomes hard, and its colour changes from yellow to red; in that state it is capable of absorbing water eagerly by capillary action. These properties explain the making of bricks from clay, and also why houses built of bricks are damp if they have no proper foundation which prevents water from rising in the walls.

Experiment 6.—Place a narrow glass tube successively into water, alcohol, and turpentine.

Observe that water will rise highest; turpentine and

alcohol will stand at nearly equal heights, though the turpentine will probably, if pure, be very slightly the higher of the two. We thus see that the action depends not merely on the fact that the solid is wetted by the liquid, but on various circumstances connected with other properties of the liquids used.

QUESTIONS ON CHAPTER XVIII

1. Describe, and give a sketch of, the shape of the surface of water and that of mercury when standing in a glass vessel.

2. Which side of a circle is convex, which is concave ?

3. How is the shape of the liquid surface in either case connected with the moistening of the solid by the liquid ?

4. If the vessels containing the water and the mercury could gradually contract more and more, what changes in the shape of the liquid surface would you expect ? Sketch what you would expect to see.

5. Describe the experiments made with tubes of different internal diameter, and the results obtained from these experiments.

6. Explain why this action is called capillary action, and give some examples of its practical use.

7. Explain how wet clay extracts spots of oil, and why it does it better than dry clay.

8. Describe what happens when wet clay is heated, first moderately and then in a furnace.

CHAPTER XIX

THE THERMOMETER—HEAT AND TEMPERATURE

Experiment 1.—Place an ordinary thermometer before you upon the table, and make an accurate sketch of it.

Observe that it consists of three principal parts :—

1. A round or elongated vessel at the lowest portion, containing mercury, or some other liquid. This vessel corresponds to the flask used in Chapter IX. (Fig. 9), and is called the *bulb*.
2. A capillary glass tube, with thick sides, corresponding to the tube in Fig. 9, part of which is full of some of the same liquid with which the bulb is filled. This tube is called the *stem* of the thermometer. The thread of mercury or other liquid seen within it is called the *column*. The position of the top of the column gives the *height* of the thermometer.
3. A *scale*, which is either engraved on the stem itself or upon the frame to which the thermometer is attached. The scale is divided into equal parts, and each of these is called a *degree of temperature*.

Experiment 2.—Place before you two vessels containing water from the tap. Note to the nearest degree the point at which the top of the liquid in the stem

stood while in air, and put the thermometer first into one vessel, then into the other, keeping your eye upon the top of the liquid thread in each case.

If you have taken care not to touch the bulb with your fingers, but to hold the thermometer at the top of the stem, or attached frame, you will observe that very little change in the height of the liquid column takes place during your experiment. We may then say that the temperatures of the water and the air are nearly the same. There is, in fact, no reason why they should be at different temperatures. Note well, once for all, that the result of every observation with a thermometer is invariably expressed by saying the *temperature* of such and such a body is so many degrees, or is higher by so many degrees than that of another body; we never say the *heat* of this body is so many degrees, or is higher by so many degrees than the heat of another body. This would be quite incorrect, for as you will understand better very soon, the thermometer does not on its scale indicate the heat required for causing one body to be hotter than another, but it tells us only that of two bodies one is hotter than another, or that they are equally hot, as the case may be.

Experiment 3.—Leave the thermometer in the water of one of the vessels and add a very small quantity of hot water to the other. Observe the height of the thermometer in the colder water, put the instrument into the other vessel, stir the liquid with it a few seconds, and note the height again. Touch the outsides of the vessels at the same time each with one hand.

If the experiment is carefully conducted, that is, if not too much hot water has been added to the second vessel, and the thermometer has been observed in both vessels very accurately, the result will be that your hands will feel no difference of temperature, but that the thermometer

will indicate a decided difference, perhaps several degrees. The thermometer will thus indicate slight differences of temperature, which our hands, that is, our bodily sensations, could not discover at all.

Experiment 4.—Place the thermometer into a dish containing snow, or into a vessel of water containing some broken ice.

The liquid column will fall rapidly, but a time will soon come when the column will neither fall nor rise; provided that there is still some snow or ice surrounding the bulb and stem. The column is then said to be *stationary*, and if you look at the degree on your scale opposite to the top of the column, you will find either a 0 (zero) or 32 opposite to it. In the latter case your instrument is called a *Fahrenheit* thermometer, in the former case it is called a *Centigrade* thermometer. This point is called one of the *fixed points* on the scale of a thermometer; it is the *melting-point of ice*, or, as it is more frequently denoted, the *freezing-point of water*.

Experiment 5.—Place two similar beakers, one containing about twice as much water as the other, side by side over a burner, so as to heat them as nearly as possible equally.

We naturally expect the smaller quantity of water to boil first; and this will of course happen. As soon as the water in one vessel boils, find its temperature and note it down. Observe, at the same time, that it will in this case also be stationary after it has reached about 212 degrees in the case of a Fahrenheit thermometer, and 100 degrees in that of a Centigrade. The water in the other vessel will clearly, as you can test, be at a lower temperature. In other words, you have heated both vessels in a like manner, that is, as nearly as possible you have conveyed equal quanti-

ties of heat to both vessels, yet they are at different temperatures.

Next wait till the water in the other vessel boils. Test it by the thermometer, and you will find its temperature also to be stationary at 212 degrees Fahrenheit, or 100 degrees Centigrade, according as your thermometer is of one or the other kind. This stationary point is the other one of the two *fixed points* of a thermometer, and is called the *boiling*-point of water.

Moreover, at 212 degrees Fahrenheit, generally written 212°F., or 100 degrees Centigrade, written 100°C., the water in both vessels was at the same temperature, but the one with more water had to be heated longer than the other, that is, more heat had to be conveyed to it to raise it to the same temperature as the other. This experiment will therefore prove to you that heat and temperature are not the same thing.

You will also now understand better what is meant by the scale of a thermometer, and its division into equal parts called degrees. The two fixed points are determined by experiments similar to ours, but much more carefully conducted; the space between these two points is divided into either 180 equal parts, called degrees, on a Fahrenheit scale, or 100 equal parts, also called degrees, on a Centigrade scale. Divisions of the same length are also carried along the stem above the boiling-point and below the freezing-point. Divisions below the point marked 0 (zero) are denoted by the negative sign –. Thus – 10° C. means 10 degrees below the freezing-point on the Centigrade scale, and – 10° F. means 10 degrees below the zero-point on the Fahrenheit scale; but as the zero-point on this scale is 32 degrees below the freezing-point, it follows that – 10° F. means 42 degrees Fahrenheit below the freezing-point.

QUESTIONS ON CHAPTER XIX

1. Describe the different parts of a thermometer, and explain the use of each.

2. Describe Experiments 2 and 3 in this chapter, and state what you consider to be their object.

3. If you were to put the bulb of the thermometer and then your hand, first to a brass door-handle and afterwards to the wood of the door itself, what do you expect to find as regards the temperatures of both objects; will they be the same or not? Try the experiment.

4. Explain how the result of the experiment just made proves that our sensations as regards temperature are not to be trusted.

5. How is the freezing-point of a thermometer fixed? What number is opposite to it on your thermometer? Is yours a Centigrade or Fahrenheit thermometer?

6. How can you roughly find whether the boiling-point of your thermometer is fixed pretty accurately? What number is opposite to it on your thermometer?

7. Describe fully how we prove that bodies may be at the same temperature and yet contain unequal quantities of heat.

8. Suppose you were to put into one of three similar beakers 1 lb. of water, into another the same weight of oil, or spirit of wine, and into the last 1 lb. of mercury, and put them all side by side into a large dish of water kept boiling, which of the three substances will be the hottest after five minutes? Which the coldest? Try the experiment and state fully what we can learn from it.

CHAPTER XX

CHANGE OF STATE AND CHANGE OF TEMPERATURE

Experiment 1.—**Heat a few grains of ordinary salt strongly in a small test-tube.**

The solid salt will melt and become liquid. When withdrawn from the flame it will become solid again. We prove by this experiment only what experience of other bodies has told us already, namely, that many solid bodies, such as wax, butter, sugar, tin, lead, and others, when heated, exchange the state of solidity for that of liquidity. Experience has also already told us that some bodies melt more easily than others; for example, butter, sugar, wax, etc. than tin, lead, copper, iron, etc. There is a certain temperature for each solid substance which is capable of being melted or fused at which it passes from the solid state into the liquid state. This is called the fusing-point of that substance. Other substances, like wood, do not melt; they are said to be chemically decomposed, or resolved by heat into other substances, before they reach the melting-point.

Experiment 2.—Place before you some salt and two beakers containing water. Satisfy yourself that the temperatures of the water and the salt are about the same. Throw a little salt into one of the beakers and stir with the thermometer till the salt is dissolved.

Observe that the water becomes colder as the salt is dissolving, the thermometer falling several degrees. A solid body has been dissolved in the water, that is, has become liquid, and the thermometer tells us that heat has disappeared. We are justified in concluding that this heat has been required for changing the state of the salt from that of a solid into that of a liquid, for this is all that has happened. If we test the temperatures of the pure water and unchanged salt before us, we shall find them nearly the same as before.

There are substances which are more soluble than ordinary salt, and if our explanation of the disappearance of heat in the last experiment is correct, we shall expect in the case of more soluble substances that more heat will be required for their change from the solid state, and that the solution will become much colder than is the case with salt.

Experiment 3.—Repeat the previous experiment with the substance called ammonium nitrate, putting a tolerably large quantity into the water.

Stirring as before with the thermometer we observe that the temperature falls through 20 or 25 degrees of the Centigrade scale, sinking as low as $-10°$ C. ($14°$ F.), that is 10 degrees below the freezing-point. The experiment proves that different substances require different quantities of heat for liquefaction.

We may possibly ask why in this case the water, being much below its freezing-point, does not freeze. The answer is: we must not forget that we have no longer water in the vessel, but a solution of ammonium nitrate, and this has a freezing-point of its own, which is still lower than the lowest temperature to which the solution falls. If we place our beaker upon a few drops of ordinary water poured on the table, we shall very soon find it frozen to the table. We shall also see that the outside of the

beaker is partly covered with hoar-frost, which is formed by the vapour of water in the air around it being first condensed on the beaker as liquid drops of water, and being then frozen by the continued fall of temperature.

Experiment 4.—Mix some salt and snow (or pounded ice) well together in a dish. Observe a thermometer placed in the mixture.

The temperature will in this case fall still lower than in the preceding experiment, probably to about $-20°$ C. ($-4°$ F.) Here the ice melts and the salt dissolves in the water produced, so that both ice and salt gradually become liquid. The consequence is that much heat is required.

Such mixtures of substances which cause a considerable fall of temperature by change of state in themselves and also in other bodies placed in contact with them are called *freezing mixtures.*

Experiment 5.—Place a test-tube half full of pounded sodium hyposulphite into a beaker containing some boiling water; remove it when the substance is all melted, and let it stand in a beaker of cold water until quite cold. Hold the test-tube in your hand, and drop into it a small fragment of the solid substance.

Observe how the fragment dropped in will at once become larger and larger by crystallisation of the liquid, which returns to the solid state, while the test-tube will at the same time be felt by the hand to become warmer and warmer as the solidification proceeds. We see thus that while heat is required for liquefying a solid, this heat is given back again when the liquid returns to the solid state. In this case all the liquid will not become solid at once, for a portion is kept fluid by the heat given up by that portion which has become solid; after some hours all will be solid again.

A striking example of this is afforded by water. Though its freezing-point is at 0° C. (32° F.) it may be cooled to more than $-10°$ C. (14° F.) if the water be previously freed from air by boiling and be then kept in a perfectly still place. But when it is slightly agitated, a portion of the liquid at once becomes ice, while the temperature of the remaining liquid rises to 0° C. Thus a portion of the water gives out sufficient heat in becoming ice to heat the rest to a temperature much higher than that at which it stood before.

Heat required by substances for changing their state is sometimes called *latent heat.* A better name is *heat of fusion*, when the change is from solid to liquid; and *heat of vaporisation*, when it is from liquid to vapour.

It should be observed here that the passage of a body from the solid into the liquid, or from the liquid into the solid state, is generally accompanied by a change of volume. Different substances behave in a very different manner in this respect. Some solid bodies contract at the moment of liquefaction, while in others the volume becomes increased when passing into the liquid state. If the solid while being heated and just before it becomes liquid floats in that portion which is already liquid, the substance must contract at the moment of liquefaction; if it sinks in its own liquid, it expands when liquefied. Ice floats upon water, as is well known; ice is thus lighter than water, or, in other words, it contracts during liquefaction. Careful experiments prove that 12 cubic inches of ice give 11 cubic inches of water when melted. This increase of bulk when water freezes, which amounts to 1 cubic foot in every 11 cubic feet of water, takes place with great force, and so produces powerful mechanical effects, of which the bursting of water pipes and the cracking of jugs containing water in winter are familiar examples.

Experiment 6.—Break up a piece of stearine candle (without the wick) into several smaller pieces, and heat them in a wide test-tube until a portion is melted.

Observe that the pieces which are still solid remain at the bottom of the test-tube. Solid stearine is thus heavier than liquid stearine, hence stearine expands during liquefaction.

Experiment 7.—Take a closed glass vessel filled up to its neck, which should be narrow, with water, and place it in a freezing mixture of salt and ice.

The vessel will soon crack and split into numerous splinters, or at any rate a portion of it will be cracked off, to allow of the expansion of the water while it freezes.

QUESTIONS ON CHAPTER XX

1. Mention some substances which have a low fusing-point, and others which have a high fusing-point.

2. How could you prove that the fusing-point of sodium hyposulphite is below 100° C.?

3. Prove by experiment that the fusing-point of wax is below 100° C., and that of sulphur above 100° C.

4. Describe fully how we show by experiment that when salt is dissolved heat seems to disappear, and state how this is explained.

5. Why does ammonium nitrate, when dissolving in water, produce a greater effect on the thermometer than ordinary salt?

6. Explain why ice and salt when mixed produce a much lower temperature than either of them had before being mixed.

7. Suppose you were to mix very hot salt with ice, could you make a freezing mixture with this salt and ice? Try the experiment.

8. What does the experiment with sodium hyposulphite teach us?

9. What is meant by latent heat? *Latent* means *hidden:* can you suggest an explanation of the use of the term for heat of fusion and heat of vaporisation?

10. Describe some interesting changes of volume which accompany change of state in some bodies.

11. If ice were heavier than water, what effect could this circumstance have upon the temperature of the air in the spring?

12. Gold, silver, and copper coins are stamped with a die. Why are they not cast in a mould, since this would be much less expensive?

CHAPTER XXI

CHANGE OF STATE AND CHANGE OF TEMPERATURE—DESTRUCTIVE DISTILLATION

Experiment 1. — Pour a few drops of spirit of wine upon the palm of your hand, after ascertaining its temperature while still in the bottle containing it.

The temperature of the spirit of wine, before being poured upon the hand, will be found to be nearly the same as that of the surrounding air. But observe that your hand has a sensation of cold where the liquid touches it. The liquid soon disappears, because it evaporates, and the vapour is invisible. We observe therefore a change from the liquid to the gaseous state. We also know from previous experiments that heat when applied to water, spirit of wine, etc., converts the liquids into vapour or gas. In the present case the heat has been supplied by the hand, hence it feels cold.

Experiment 2.—Repeat the experiment, using successively oil, water, and ether.

You will find that no effect is noticeable in the case of the oil, while the ether evaporates rapidly, withdraws much heat from the hand, and gives a very marked sensation of cold. The oil does not evaporate, the water does, but not so readily as either the spirit or the ether. Liquid bodies which are like ether, spirit of wine, and

water are called volatile bodies; they are converted by heat into vapour, and by cooling the vapour they return unchanged to the liquid state. Bodies like oil, which cannot be converted into vapour by heat, or which if they are converted into vapour cannot be reconverted into the original liquid by cooling, are called *non-volatile.*

Experiment 3.—Into a cylindrical glass vessel (Fig. 18) pour some cold water, so that it stands at A. Note the temperature of the water, and add boiling water till the level reaches B. After shaking the vessel well take the temperature again.

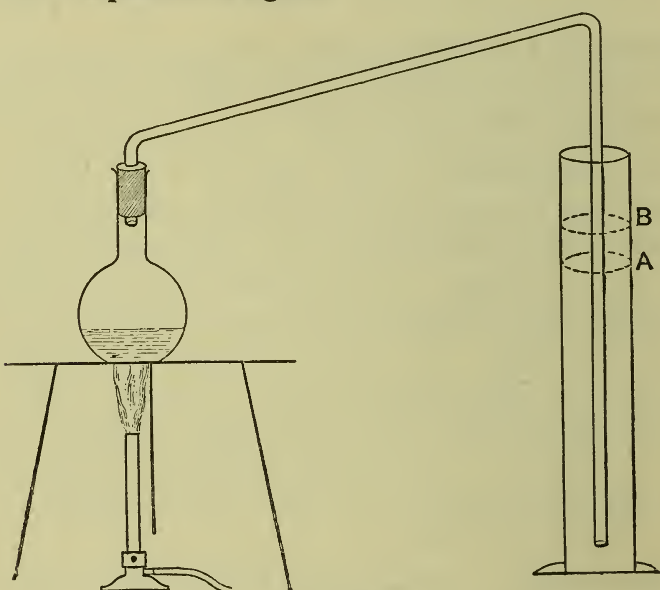

FIG. 18.

You will find that the admixture of a small portion of boiling water has, as we should expect, raised the temperature a few degrees. Note the difference of the two temperatures.

Experiment 4.—Into the same vessel pour the same quantity of water as in the previous experiment. Take

the temperature again. But now instead of boiling water pass steam from a flask in which water is boiling into the vessel until the water stands again at the height B. Take the temperature after thoroughly shaking the water.

The difference between the temperature of the water when cold and that after some steam has been passed into it will be very much greater than in the previous experiment, in which a like quantity of hot water has been added. But the steam as it leaves the boiling water has the same temperature as the boiling water itself, as we may easily conclude from the experiment in a previous chapter, when we observed the temperature of boiling water with our thermometer. This temperature was seen to be constant at about 100° C. (212° F.), and the thermometer did not rise while passing through the steam above the boiling water in the flask. Whence then is the difference observed in our present experiment? It is easily explained by considering that when water is kept boiling in an open vessel its temperature remains constant, and the heat supplied goes to change the water from the liquid state to the gaseous state. For this purpose a certain quantity of heat is required, namely the latent heat, or heat of vaporisation, and it is this heat which is given back again to the water in the cylinder, where the steam from our flask, as it arrives in the colder water, is speedily reconverted from the gaseous state into the liquid again. Hence the water will become much hotter than if an equal quantity of merely boiling water had been added. Indeed, by passing into cold water sufficient steam we could make it boil in a wooden vessel; 1 lb. of steam will in this way raise more than 5 lbs. of ice-cold water to the boiling-point.

Experiment 5.—Tie a little muslin round the bulb of your thermometer and observe the temperature. Drop upon the muslin a few drops of water and observe the

temperature again. Repeat the experiment with drops of spirit of wine and ether. Note in each case the lowest temperature obtained.

This experiment gives you the same result as the experiment in which you dropped the liquids upon your hand; but the differences of temperature observed by the thermometer are a more accurate means of comparing the effects produced than sensations of the hand.

Experiment 6.—Place some colza oil into a flask; connect the flask with the apparatus for distilling water, and heat it.

Observe that the oil will appear to boil. A vapour will be given off which will condense in the tube, and part of the liquid formed will run down into the vessel placed there to receive the "distillate," while some portion of it will form a crystalline deposit in the interior of the tube. The oil will be completely vaporised, except a small brownish residue in the flask in which it is heated.

But observe further that the liquid received in the vessel differs strikingly in all its properties from the oil from which it has been derived. Smell it carefully and you will observe that it has a sharp pungent smell, which produces coughing and makes the eyes water. Moreover, the solid crust formed in the interior of the tube may be rendered liquid by heating it separately.

The result is thus not a simple distillation like that of water, but a production of new bodies, or a chemical decomposition of the heated oil. This operation is similar to the action of heat upon solid wood in a previous experiment; such an operation is called *destructive distillation.*

Experiment 7.—Collect a quantity of rose-leaves (or the petals of pinks, fresh peels of lemons, fennel seeds, or caraway seeds) and place them with a quantity of water into a flask. Distil the water.

The distillate has the odour of rose-leaves, or of the other substances employed. These substances are not completely volatile, but, as we see, must contain volatile matter, which may be removed from the remainder by distillation. Certain parts of many other plants have the same property. If larger quantities of these substances are distilled, oily matter collects on the water in the receiving vessels, which is called, according to its source, oil of roses, oil of cloves, etc. All these are volatile oils, capable of being distilled like water.

QUESTIONS ON CHAPTER XXI

1. What happens in each case when water, oil, spirit of wine, and ether are poured in succession upon the bulb of a thermometer ? In which case will the thermometer show the least, in which the greatest change ?

2. Describe what you expect to happen when a little warm spirit of wine is poured on the bulb. [Try the experiment, slightly warming a very little in a test-tube and pouring it upon the bulb.]

3. Describe fully how we accurately prove that the steam given off by boiling water is at the temperature of 100° C., and yet contains more heat than an equal quantity of boiling water.

4. Describe the products obtained by distilling colza oil.

5. In what respects is the last operation similar to that of heating wood in a test-tube ? What products were obtained in this case ? Why are both operations called destructive distillation ?

6. What is meant by a *volatile* oil ? Mention some, and state from what bodies they are obtained and in what way.

7. An oily-looking liquid is given to you. How would you proceed to ascertain if it is volatile or non-volatile ?

8. How would you prove by experiment that wood and coal are very nearly the same substances ?

CHAPTER XXII

HEAT AND CHEMICAL ACTION—FLAME

Experiment 1.—Place a few sticks of caustic potash into a beaker containing a little cold water. Stir the liquid with a thermometer.

The thermometer will be seen steadily to rise while the potash dissolves. This result appears to be an exception to the rule that when solids dissolve heat is required and the solution therefore becomes colder than the water was at starting. The solution of potash is, however, different in an important respect from a solution of salt, or of ammonium nitrate. We may regain the dissolved salt, etc. in an unaltered state by simply allowing the water to evaporate. No chemical change therefore occurs in those bodies through the process of solution; it is solely a change of state. But the potash cannot be obtained again in its former state; the water will not separate completely from it if we allow the liquid to evaporate. Hence we conclude that water and caustic potash enter into chemical union; and since there are other instances within our experience of chemical union accompanied by heat—for example, the union of quicklime with water, and the burning of a candle—we can explain the apparent exception thus: the potash dissolves in water, and no doubt by changing its state from that of a solid to that of a liquid takes up heat for the purpose; but it also unites chemically with the water, thus

producing heat, and the heat developed by this union is more than that required to make the solid potash liquid; hence we find that the solution becomes warmer.

Experiment 2.—Expose a little dry caustic potash to the air in a small dish.

It soon becomes moist, and will gradually change to a thick liquid. On keeping it for some time it will also, upon the addition of a little vinegar or other acid, give up carbonic acid in bubbles. The potash combines with the vapour of water in the air and also with the carbonic acid in it. Bodies which, like potash, attract moisture from the air are called hygroscopic (Greek, *hygros*, wet; *skopeo*, to view), and the substance is also called deliquescent, since it becomes liquid by absorbing moisture. It is through the possession of these properties that potash may be used to remove carbonic acid and vapour of water from a mixture of gases which contains either or both of them. Calcium chloride, used in a previous experiment, is still more hygroscopic than potash, but does not retain carbonic acid.

Experiment 3.—Place two beakers before you and pour into one a small quantity of water, into the other an equal quantity of sulphuric acid. The temperature of both liquids will be seen to be nearly the same. Now pour the acid into the water (*not* the water into the acid). Take the temperature of the mixture by your thermometer.

Observe the great rise of temperature. Here no change of state takes place, hence we must conclude that the heat produced is due to some strong chemical action between the acid and the water. Experience shows that water, both when in the liquid and in the gaseous state, is eagerly absorbed by sulphuric acid, and that the absorption is always accompanied by a rise of temperature. Hence practical advantage is taken of this property; if a gas

is to be dried which has no tendency to enter into chemical union with sulphuric acid, it is allowed to bubble through this liquid contained in a vessel like that in Fig. 13, the gas entering at *b* and leaving at *a*; similarly, if from a closed space the moisture is to be completely removed, it is usual to place within it a dish containing sulphuric acid.

The production of heat by chemical union will explain how it is that a candle or a heap of coals will go on burning when we have once, by means of a burning match, set fire to the smallest portion of it. The lighted match heats the end of a candle or a corner of a piece of coal, and starts the chemical union between the oxygen in the air and the carbon and hydrogen contained in the substance of the candle or the coal; the heat produced by this union maintains a temperature sufficiently high to enable another portion of the substance to enter into union with oxygen, and thus the whole process goes on while any fuel is left. But the heat of the lighted match really first of all decomposes a small portion of the combustible substance, and converts it into gas; it is this gas, not the substance itself, which burns. Candles, pieces of paper, or lumps of coal, are, when burning, like gas-works in miniature; for gas is first made from each of them by the application of heat. This gas then combines with oxygen and gives out more heat, and this combination of gases, accompanied by heat and light, is what we call flame. Bodies not capable of assuming the state of gas do not really burn with flame.

Experiment 4.—Slightly damp a piece of writing-paper and press it down upon a candle-flame. Take it off again quickly.

Experiment 5.—Hold a piece of wire-gauze for a minute across the flame of an ordinary gas-burner, such as is used for heating flasks.

Observe that the paper will be found to be charred in a ring with an unblackened spot in the middle; and in the second experiment that the wire gets red-hot in a ring, while a dark portion obviously less hot is in the middle. Both experiments prove that the middle of the flame is not so hot as the edges. The flame, on carefully studying its appearance, has a dark central part which seems hollow. Flame exists where the oxygen meets the body which combines with it; and this takes place most readily at the outer edge.

Experiment 6.—Hold a little glass tube, three or four inches long, in a slanting direction, with one end in the dark space in the middle of the flame of a candle. After a few minutes put a lighted taper to the free end.

A flame will appear at that end, proving that some substance in the form of a gas, which burns like the original flame, is passing along the tube from the hollow space inside the flame. This substance is nothing else but the material of which the candle is made turned into gas by the heat of the flame. If you blow out a candle, and have a lighted taper ready, you can relight it by quickly holding the taper a few inches above the wick.

Experiment 7.—Press a small china dish quickly upon the flame of a candle or fish-tail gas-burner, and hold it there for a few minutes.

A black spot will in either case be formed upon it; the black substance may be scraped off and will be recognised as soot or carbon, very similar to the charred substance left in the test-tube in a previous experiment, when some wood was heated in it.

Experiment 8.—Repeat the same experiment with the burner used in Experiment 5.

No soot is deposited as long as the holes near the foot

of the burner are open. Close them with the fingers or by turning the ring provided for this purpose, and soot will be at once plentifully deposited. But we notice another difference between the flame which deposits carbon and that which does not. The first gives out light, it is *luminous* (Latin, *lumen*, light); the flame which deposits no carbon gives out no light, it is *non-luminous.* We conclude that the luminous flame contains carbon floating in the flame in a very hot state, so as to give out light; the non-luminous flame cannot contain carbon, for none is deposited under similar circumstances, nor is there any light. The only cause of these differences must be looked for in the circumstance that to produce the non-luminous flame we kept the holes near the foot of the burner open; air, and therefore the oxygen which it contains, can thus mix abundantly with the gas, and hence the carbon is so completely burnt to carbonic acid that neither light nor soot can be obtained. There is, in this case, therefore, a greater amount of chemical action than in the case of a luminous flame, and if our reasoning is correct, we should expect more heat to be produced by a non-luminous flame than by a luminous one. Now this is really the case; the non-luminous flame is much hotter than the luminous flame, as has been proved by experiments in which the temperature of either is accurately determined by suitable instruments.

QUESTIONS ON CHAPTER XXII

1. Describe the result obtained by dissolving caustic potash in water. What is there apparently exceptional in this result? Explain it.

2. What is the meaning of the word "hygroscopic"? Mention some hygroscopic substances, and explain how they are employed for practical uses.

3. What happens when sulphuric acid is poured into water? How is the result explained?

4. By what experiments is it proved that the highest temperature of a flame is at its edge? How is this fact explained?

5. By what experiments is it shown that a candle is converted into gas before it burns?

6. Explain what is meant by a *luminous* and what by a *non-luminous* flame?

7. To which class would you reckon the flame of burning hydrogen to belong? What explanation would you give of the similarity in appearance between a hydrogen flame and the flame of a gas-burner when air is admitted?

8. Which flame of a gas-burner is the hotter of the two? How would you explain it?

9. What is the object of blowing air into a coal fire? What effect is produced by doing it?

10. What substances are contained in ordinary smoke as it leaves the chimney-pot of a dwelling-house? How does each substance get there?

CHAPTER XXIII

CONVECTION, CONDUCTION, AND RADIATION OF HEAT

Experiment 1.—Take hold of a long narrow test-tube, nearly full of water, by the middle, and heat the upper portion only of the water by holding the tube obliquely over the flame of a burner.

Observe that the water at the top will become hot, and will even be seen to boil when heated long enough, while no inconvenient rise of temperature is felt by the fingers below the hot part. We can, from the teaching of previous experiments, easily explain this result. Water expands when heated and is then lighter, bulk for bulk, than colder water. Hence when water, or any other liquid, is heated near the surface, the heated particles remain at the surface, while the heavier and colder particles continue at rest where they are.

Experiment 2.—Repeat the last experiment, but apply heat at the bottom of the tube.

It will soon be impossible to hold the tube, for the water in the part near the fingers will become hotter and hotter. In this case, the lowest particles, being heated first, become lighter by expansion and rise to the surface, while the colder particles at the top sink down to take the place of those which have risen. Thus a complete circulation of the water in the tube takes place.

Now in this case, which is an example of the usual way in which liquids and gases are heated, the upper portion of the substance is not heated by being close to the flame. That portion which is nearest the source of heat receives heat first, and at once begins to move upwards, taking the heat which it received with it, and sharing it with the colder portion, whose temperature thus gradually rises. The heat is thus, as it were, "conveyed" from below upwards, and hence this mode of heating substances is called *convection* (Latin, *conveho*, to carry along with). The condition that this process should be possible is, of course, that the particles to be heated should be easily movable amongst themselves, hence solid bodies cannot be heated by convection.

Experiment 3.—Repeat the first experiment, but fill the test-tube nearly full of mercury instead of water.

In a very short time you will not be able to hold the middle of the test-tube in consequence of its rapidly becoming nearly as hot as the top; nor can the bottom of the test-tube be now touched without its manifesting a considerable rise of temperature.

Here something else must clearly be going on in which mercury differs from water. The upper portion of the mercury remains on the top, being more heated and therefore lighter than the lower. Yet heat rapidly passes downwards. Since no circulation is possible, the heat passes from particle to particle of the mass, the hotter particles at the top giving up heat to the colder particles below them, these to the next layer, till much of the heat applied at the end near the flame arrives at the other end, flowing downwards as it were like a little rivulet upon a sandy slope, which becomes less as it runs along, but yet carries some water down. This mode of heating bodies is called *conduction* (Latin, *conduco*, to lead along). It goes on in water as well as in mercury, but at a widely

different rate, being much slower in the water than in the mercury.

Bodies which allow heat to travel very rapidly in this way are called *good conductors;* all metals are good conductors, though even they differ somewhat in this respect, silver and copper being much better conductors than lead or platinum. These last metals again conduct heat much better than wood, glass, stones, and other solids, which are *bad conductors.* All liquids except mercury, and all gases are very bad conductors indeed.

Experiment 4.—Hold two thin wires about three or four inches long, one of iron and the other of copper, at one end between the thumb and the forefinger, one wire being in each hand, and heat the other ends in a flame.

This experiment shows very clearly the difference in conducting power between the two metals. The copper wire soon becomes so hot that it no longer can be held in the hand, while the iron wire may still be held without inconvenience. Hence copper is a better conductor of heat than iron, for in the copper wire the heat flows more quickly from one end to the other than in the iron wire.

Experiment 5.—Hold your open hand palm downwards as high above a flame as you can, and lower it gradually. Estimate, or measure roughly, the distance above the flame at which the temperature becomes unbearable.

The heating of your hand is in this case due to convection of heat by gases. The gases produced by the chemical action in the flame are hot and rise upwards, while the surrounding colder air rushes into the space to give up its oxygen.

Experiment 6.—Put your hand at the side of the

flame, at the same distance from it as that determined in the preceding experiment, and bring it gradually nearer and nearer the flame.

Observe that you can bring your hand much nearer now. Consider that no hot gases from the flame can reach your hand, because the cold air flows past your hand towards the flame, while the hot gases rush upwards; of these only a very small part rises between your hand and the flame, the much larger part rises right above the flame. Whence then is the heat we feel, which cannot be due to conduction? The heat which thus passes through a substance, in this case air, without really warming it, but which warms some object at a distance from the source of heat, is called *radiant* heat, and this process of sending out heat from a hot body to other bodies is called *radiation* of heat. The heat which we receive from the sun reaches our earth through the immense space between the sun and the earth by radiation.

Our flame illustrates all the three modes by which heat may pass from one point to another. Above the flame heat reaches us by convection; at the side of the flame by radiation; and below the flame the burner itself is hot in consequence of conduction, very hot, as we shall find, at the points nearest the flame, less and less hot as we put our hand nearer to the foot of the burner.

Experiment 7.—Cut off five or six pieces of the same length, about three or four inches, from a thin iron wire, and straighten them. Collect all except one of them into a little bundle, and heat one end of the bundle and one end of the remaining wire in a flame as in Experiment 4.

The single wire can be held for almost any time, but the end of the bundle which is held in the hand soon becomes inconveniently hot. The reason of it is this: at first, when the bundle and the single wire are put into the

flame, the single wire, which of course requires less heat than the whole bundle to raise it to a certain temperature, becomes hot more quickly at the heated end than the bundle; still both soon acquire at that end a fixed temperature, namely, that of the flame. Thus, at the source of heat, the single wire is in the same condition, as regards temperature, as each wire of the bundle. But with reference to what happens between the flame and the hand, the wires of the bundle are in a different condition from that of the single wire, for every wire of the bundle is more or less shut in by the rest, and therefore does not expose so large a surface to the air as that of the single wire. The result of this is that each wire of the bundle loses less heat by convection and radiation than that lost by the isolated wire; in other words, more heat reaches the end of the bundle held in the hand than the end of the single wire, that is, the end of the bundle is hotter.

Experiment 8.—Heat the ends of two iron wires of the same length, about three inches, but one much thinner than the other, in the flame, as in the last experiment.

The thick wire will soon get much hotter than the thin one at the end which is held in the hand. In fact it behaves, compared with the thin wire, just as the bundle did under the similar circumstances of the preceding experiment. Now a thick wire may be regarded as a bundle of thin ones held very closely together; hence the explanation given of the result of the last experiment applies to this case also.

Experiment 9.—Bring your open hand near to the non-luminous flame of a gas-burner, as in Experiment 6, until you begin to feel the heat radiated. Now turn the ring of the burner so as to produce a luminous flame, while still holding the hand in the same position as before.

Observe that your hand will feel that more heat is radiated by the luminous flame than by the non-luminous, although the latter is really the hotter of the two. But the two flames differ in their nature ; in the luminous flame we have hot solid carbon ; in the non-luminous flame we have hot gases, and we thus learn that solid bodies radiate heat much better than gases, even if these are at a higher temperature than the solids. Different substances differ considerably in their *radiating power*, just as they differ in their conducting power, and in many other natural properties.

QUESTIONS ON CHAPTER XXIII

1. Describe the different effects produced when a vessel containing water is heated (*a*) near the surface of the water; (*b*) near the bottom.

2. A piece of ice has a little lead wire wrapped round it so as to make it sink in water, and is dropped into a test-tube containing water. Explain (1) why the ice does not melt when the test-tube is strongly heated at the top; (2) why the water does not get warm until after some time, when the test-tube is heated at the bottom.

3. In what respects do you know the properties of water to differ from those of mercury?

4. Arrange in the order of their powers of conducting heat the following substances: *iron*, *lead*, *water*, *copper*, *marble*, *mercury*, *air*, *silver*, *glass*, placing the best conductor first upon the list.

5. Suggest an experiment by which you could find out whether silver or copper is the better conductor.

6. Explain the difference between convection and conduction, and describe experiments for showing this difference.

7. Why is the air of a room in which a fire is burning hotter near the ceiling than in other parts of the room? Why in the upper part of the room opposite to the fire?

8. Why does a thin wire of copper, when held with one end in the flame, not get so hot at the other end as a thick wire of the same length held in the same flame?

9. Make a sketch showing how convection of heat can be made use of in warming a house by means of hot-water pipes.

10. Explain why the flame of a burner when rendered luminous radiates more heat than when non-luminous.

CHAPTER XXIV

MAGNETIC ACTION

Experiment 1.—Suspend two steel knitting-needles about a foot apart and two or three inches above the table, by fine threads at their middle points, so that they hang in a horizontal position and are free to swing.

Both needles when at rest will point to different directions, which may be altered by turning the support by which they are suspended to the right or to the left, and allowing the needles to come to rest again. In other words, we may make them point in any directions we choose, which may be parallel to each other or inclined at any angle.

Experiment 2.—Suspend in the same manner other bodies of a shape similar to that of the needles, such as thin glass tubes, lead pencils, or a foot of stout brass or copper wire.

These bodies will behave exactly like the needles; they can be made to point in any direction you like.

If you displace either the needles or the glass tubes etc. after they have come to rest, by gently pushing aside one of the ends, you will observe that they each return to the position which they took up when at rest. The reason is that the thread is twisted, and the twist acts upon the suspended needle. In pushing the end of the suspended body

aside, you either untwist the thread or twist it more than it was before, and in either case the thread tends to return to its former state, thus acting upon the suspended body.

Experiment 3.—Again suspend one of the needles, a glass tube, etc., in succession, and bring near to one end of each body the end of a straight magnet.

The magnet will exert some action upon the knitting-needle, but none upon the other bodies. The end of the needle will be "attracted," that is, it will come nearer to the end of the magnet, and finally cling to it. The same action takes place when the other end of the magnet is brought near to the same end of the needle, or either end of the magnet is brought near to the other end of the knitting-needle. If instead of the magnet any other piece of iron be brought near to the same needle, no action whatever can be observed.

Experiment 4.—Suspend the magnet itself in the same manner as the other bodies, and bring one end of a needle near to either end of the magnet.

The needle will attract either end of the magnet. Thus the action between magnet and steel is mutual. Observe also the direction in which the magnet came to rest when suspended: one end will point towards the north, the other towards the south.

Experiment 5.—Bring the *middle* of the magnet near to either end of the needle.

No action is observable. The magnetic action exerted by a magnet on a steel needle seems chiefly to reside in its extremities, which are called the *poles* of the magnet. One is called the *north* pole, viz. that pointing towards the north in the preceding experiment, and the other the *south* pole. The middle is called the *neutral* part; a line across the magnet through the middle, the *neutral* line.

Experiment 6.—Place one of the knitting-needles upon the table, and draw the north pole of the magnet ten or twenty times from the middle to one end of the needle; then place the south pole upon the middle and draw it an equal number of times to the opposite end. Mark this end by a scratch with a file, and suspend the needle.

The needle is magnetised by this process, and behaves as the magnet did; it will now come to rest in a definite position when suspended, the *marked* end pointing towards the north. It will also, if taken down, attract with each of its ends either end of the other needle.

Experiment 7.—Magnetise the other needle in the same way as in the preceding experiment, and mark that end which has become a north pole. Bring this end near to the north pole of the suspended needle.

The two poles act upon one another, but the action is one of "repulsion." If the other end be brought near to the south pole of the suspended needle, repulsion will likewise be observed. On the other hand, if the marked pole be brought near to the unmarked pole of the suspended needle, attraction will take place. Hence we conclude that like poles of magnets repel, unlike poles attract one another. Moreover, we see that the same end of a magnet may cause both attraction and repulsion. This twofold action, whenever it is manifested by bodies, is described as *polarity*, or *polar action.*

Experiment 8.—Break one of the needles into two parts across the middle, and observe the action of each of the four ends on the poles of the other needle.

You will find that each portion is a complete magnet with two poles, and the poles of the two magnets will lie in the same direction as the poles of the original magnet. If these new magnets are broken again into two halves,

each half will be again a complete magnet, and however often the process of breaking is repeated the same result ensues, each portion remaining a perfect magnet. We may therefore conclude that the smallest part of a magnet contains a north pole and a south pole.

Experiment 9.—Suspend a knitting-needle so that it hangs perfectly horizontal, and points east and west. Now magnetise it strongly and suspend it again.

Observe first, that it now points towards the north, as the magnet did in a previous experiment; in the second place, that its direction is no longer horizontal, but that the north pole *dips* downwards. If we gently displace the needle with the finger and then leave it to itself, it will return to the definite position it first took up after being magnetised. If we turn the point of support to the left or right, the needle will return and point north and south, its behaviour thus differing from that of an unmagnetised needle and, moreover, proving that that action exerted on the needle which impels it to assume a north-south direction must be stronger than the twist of the thread by which it hangs.

Experiment 10.—Place the south pole of a strong straight magnet underneath the north pole of the knitting-needle and a few inches to the right or left, so that the effect is noticeable without being too strong.

The pole of the needle will point in a new direction, neither towards the north nor to the pole of the magnet beneath, but somewhere between the two; it will also dip downwards a little more than before. The needle behaves as if it were now under the influence of two magnets acting jointly upon it; but as only one magnet visibly affects the needle, we must conclude that the earth itself behaves like a magnet, its south pole being situated in that region to which the north pole of a suspended magnetised needle points.

Experiment 11.—Suspend a small magnetic needle over the middle part of a long straight magnet, and slowly move it along the magnetic bar, first to one pole of it, then back to the other pole.

Observe carefully the behaviour of the small needle in various positions. While it is over the middle its north pole is directed towards the south pole, and its south pole towards the north pole of the larger magnet, and in this position it is perfectly horizontal. At some distance from the middle, between it and the north pole of the magnet, its south pole begins to dip downwards, and as it comes nearer to the north pole the angle at which it is inclined to the horizon increases, until it hangs vertically, when its south pole is over the north pole of the magnet. On the opposite side of the bar magnet, between its middle and its south pole, the north pole of the needle dips, and its behaviour, while being moved along, is exactly the counterpart of that of the south pole before.

We are thus able, from the two preceding experiments, to assign a cause for the behaviour of a magnet which is freely suspended. It behaves exactly as if our earth were a large magnet, its south pole being near to the geographical north pole. Observations made at many places on the earth have proved that a magnet freely suspended behaves exactly as our little magnet did in the different positions given to it in the last experiment.

It will also be clear from our experiments that a freely suspended magnet may be used for determining the direction of north and south on the earth, a fact of the greatest importance for navigating ships across a wide sea. A magnetic needle used in this way is called a *compass*.

Experiment 12.—Strew a layer of iron filings on a flat surface, and lay a straight magnet on them. Raise the magnet by its middle point.

Large tufts of filings will be found to cling to the poles, but they gradually and regularly diminish in size from either pole towards the centre, at which place none are to be found. Now these filings were not previously magnets, and are no longer magnets when shaken off again. On the other hand, only a limited number of them really touch the larger magnet; those that are touching it seem to become for the time little magnets themselves, capable of acting upon the filing next to them in the same way, this again upon the next, and so on. We notice here a new kind of action of a body upon another, viz., that it may transfer some of its own capabilities to other bodies in its neighbourhood, just as a teacher acts upon a pupil.

When a magnet causes another body, in contact with it or in its neighbourhood, to become a magnet, it is said to *induce* magnetism in that body; it influences it and makes it like itself, and this action is called *induction*. Now, as attraction, and never repulsion, occurs between a magnet and an unmagnetised piece of iron or steel, we must conclude that the magnetism induced in the body near to the inducing magnet is such that opposite poles are adjacent; that is, a north pole induces a south pole nearest to itself, and a south pole induces a north pole.

QUESTIONS ON CHAPTER XXIV

1. A straight bar, painted so that its material cannot be seen, is supposed to be either iron or some other metal. What experiment would you make to decide the question?

2. What object is there in suspending a glass tube, etc., and bringing a magnet near, in Experiment 3?

3. How do we prove that the action between an ordinary bar of steel and a magnet is mutual?

4. Describe accurately how you would make a magnet of a needle by means of another magnet.

5. If you draw the north pole of a magnet along the blade of your penknife, beginning at the handle and ending at the point: will the point be a north pole or a south pole? Where is the other pole? How could you prove your answer by experiment? Perform the experiment.

6. Describe fully the effect of breaking a magnetised needle into four parts, and show by a drawing where the north and south poles of each little magnet are, assuming that the pieces are not moved but that each piece is left in the exact position which it had when it formed part of the needle before the experiment.

7. Describe completely the experiments which lead to the conclusion that our earth is a large magnet. Where is the north pole of the earth considered as a magnet? How could you prove this?

8. What is a compass? For what purposes is it used?

9. Explain what is meant by *polarity* and by *induction*, describing experiments on either.

10. Suppose three similar magnets were suspended at their middle line, one near the geographical north pole of the earth, one near the equator, and one near the geographical south pole: what position would you expect each of them to take up? Draw the position of each, showing which is the north pole and which the south pole of each magnet.

CHAPTER XXV

ELECTRIC ACTION

Experiment 1.—Suspend a wooden stick horizontally by means of a paper stirrup and a silk thread, and bring a stout glass rod near it.

No action between the two bodies is perceptible. The case is somewhat similar to the holding of an unmagnetised knitting-needle near some iron filings. Something will have to be done to the glass rod before any action can be seen to take place.

Experiment 2.—Rub the glass rod briskly with some dry warm silk and again hold it near the suspended stick.

The stick will move towards the glass. The glass rod is now manifestly in a different state, and in this is capable of attracting other bodies which can move freely. This new state is called a state of *electrification*, or the *electric* state—from the Greek *electron*, amber—because the power of attracting bodies here excited in the glass was observed by the ancient Greeks to be exhibited by rubbed amber. As long as bodies are in their usual state they are said to be *neutral*, or non-electrified. To change this state we must *electrify* them by certain operations, of which rubbing with some different substance is one. The bodies are then spoken of as *electrified*, or electrically excited. The action

itself is said to be due to *electricity*, and in this instance to *frictional* electricity, since the electric state of the glass rod was produced by friction—that is, rubbing.

In this case, as in that of magnet and needle in the last chapter, the action between the electrified glass and the stick is mutual. This can easily be seen by placing the rubbed glass in the stirrup and bringing the wooden stick near it. The glass will be attracted by the stick.

Experiment 3.—Rub a long stick of sealing-wax with dry warm flannel and hold it near the suspended wooden stick.

The sealing-wax is now electrified and acts upon the stick as the glass rod did. Here also the action can be shown to be mutual by suspending the rubbed sealing-wax and holding the stick near it. If instead of the wooden stick, the hand, a metal spoon, or any other non-electrified body be held near the suspended sealing-wax, the sealing-wax will still be attracted, and by properly moving the neutral body may even be made to turn round and round.

Experiment 4.—Suspend a rubbed glass rod and bring another rubbed glass rod near it.

Observe that in this case also an action takes place, but it is one of repulsion. We know that a rubbed glass rod and a neutral one attract each other, for we have seen that attraction takes place between an electrified body and any other body in the non-electrified state. From the present experiment it would, however, appear that between one electrified body and another electrified body repulsion takes place. But if, in order to test the truth of this conclusion, we bring an electrified rod of sealing-wax near the electrified glass rod, instead of repulsion a more powerful attraction will be observed than if the glass rod were neutral. We must therefore extend our experiments further if we would discover the whole truth.

Experiment 5.—Suspend a rubbed stick of sealing-wax and bring another rubbed stick of sealing-wax near it.

Repulsion will be observed to take place between two pieces of rubbed sealing-wax as between two pieces of rubbed glass. Other bodies show the same behaviour when similarly experimented on. Hence we may so far conclude that substances of the same kind electrified in the same way repel one another. We must be careful to add "electrified in the same way," for as our knowledge of the subject increases we shall become satisfied that there may be attraction even between electrified substances of the same kind if one has been electrified in one way and the other in a different way.

On the other hand, we must now inquire if attraction always takes place between two electrified substances of different kinds.

Experiment 6.—Rub a stick of sealing-wax and a stick of sulphur (or of ebonite); suspend either in the stirrup and bring the other near it.

In this case repulsion will be observed to take place. In fact, we must make special experiments with each kind of body and observe what takes place. We shall then find that all bodies may, after being rubbed in a given way, be arranged in two great groups; each body included in one group repels every body in the same group, but attracts every body in the other group. Since thus two different kinds of action between bodies are observable between electrified bodies, and the cause of these actions is called electricity, we are led to assume that there are also two kinds of electricity, or rather electrical states, and that bodies in the same state repel one another, while those in opposite states attract one another. This law of nature is usually expressed by saying: *like electricities repel, opposite electricities attract one another.* One of these electrical

states, that of glass when rubbed with silk, is said to be due to *positive* electricity, that of the sealing-wax when rubbed with flannel to *negative* electricity; the glass is described as "positively charged," the sealing-wax as "negatively charged."

So far as we have gone at present, we also see from our experiments that while magnetic action takes place only between a very few substances, electric action appears to take place between all kinds of matter. On the other hand, the two actions resemble each other in manifesting themselves between bodies at appreciable distances from one another.

Experiment 7.—Place a few small bits of paper upon the table, rub one end of a glass rod and hold first the rubbed end near to the scraps and afterwards the other end.

The bits of paper are acted on by the rubbed end and fly up to it, but as soon as they touch the rod they are strongly repelled. The attraction which is at first shown is very similar to that observed when a magnet is held near to a suspended steel needle or to iron filings spread upon the table. A magnetic state is induced in that case in an unmagnetic body, a pole of the magnet inducing an opposite pole near it, and hence the attraction. We are therefore justified in assuming, and shall soon prove by further experiments, that the ends of the bits of paper near the excited rod became electrified by induction, and since the glass is positively electrified, the ends of the paper will be negatively electrified; hence attraction will take place. But on touching the glass they fly back again; this repulsion can only be due to their becoming positively electrified when touching the glass rod. Hence bodies become electrified not only by friction but also by touching another body which is already electrified.

On bringing the end of the glass rod which has not

been rubbed near to the bits of paper, no action whatever is observed. It thus appears that the power of exciting electrical attraction resides in glass at that portion only which has been electrically excited; it does not spread farther; hence glass is said to be a *non-conductor* or *insulator* of electricity. Other bodies—for example, metals, the human body, etc.—are called *conductors*, because the state of electrification when excited at one part spreads itself over the whole body.

Experiment 8.—Suspend a small round bit of cork or elder pith by a silk thread to the end of a thin glass rod, supported on a wooden foot and the upper part bent so as to make a right angle, and hold a rubbed glass rod near it.

The suspended bit of cork is first attracted by the glass rod, and after touching it repelled. That the ball is now electrified is shown by bringing the hand near it; it will be attracted by the hand. When touched by the hand, however, the ball loses its electricity.

If the same experiment be repeated, using a cotton thread and stiff metal wire instead of the silk and glass for the purpose of suspension, the ball is attracted but never repelled, because any electricity which is communicated to it by the glass rod when touching it disappears at once through the cotton thread and metal to the earth, since these are good conductors.

A small round bit of cork or elder pith suspended by a piece of dry silk is called an *electrical pendulum*, and it is frequently used, first, for showing whether a body brought near it is electrified or neutral; and secondly, if electrified, whether positively or negatively. In order to determine the kind of electricity possessed by a body we must first touch the ball with a body known to be either positive or negative; the behaviour of the pendulum—that is, whether it is attracted or repelled by the body whose charge we

wish to examine—is then observed by bringing the body near it. If the pendulum, for example, were previously charged with positive electricity, and is repelled by the body brought near it, we would conclude that the body is charged positively; if attracted, the body is most probably charged negatively. In this last case we have, however, no absolute certainty, for we have already seen that attraction is observed between a charged and a neutral body.

It is thus very desirable for the purpose of experiments on electricity to set up several electrical pendulums; say two with silk suspension and glass supports, of which one may be charged positively, the other negatively, so that we may produce repulsion whatever the charge on the body; while another with a cotton suspension and metal support—that is, a conducting suspension—will be useful for the next experiment and for others.

Instruments which, like these pendulums, are capable of indicating an electric charge and its kind, are generally called *electroscopes.*

Experiment 9.—Insulate two coins by fixing them in a horizontal position upon the ends of sticks of sealing-wax; attach the other end of one stick to the table or to a small board, and hold the second stick in your left hand so that the edges of the two coins touch. Hold a rubbed glass rod with your right hand near the coin on the fixed stick and separate the two coins before removing the rod.

If both coins successively are, without being touched, brought near to the pendulum which has a conducting suspension, they will both be found to be charged. In order to ascertain the kind of electricity with which they are charged, positive electricity is communicated to an electrical pendulum with an insulating suspension by touching it with a rubbed glass rod and the experiment then repeated. It

will be found that the coin fixed upon the stick which was held in the hand will repel the pendulum, thus proving itself to be positively charged. The coin upon the fixed stick of sealing-wax will prove itself to be negatively charged, both by attracting a positive and by repelling a negative pendulum.

This action of an electrified body upon neutral bodies at a distance is very similar to that of a magnet upon a bar of steel or iron near it. In this case an electrified body *induces* in other bodies a change in their state with regard to electrification, hence this action is called *electric induction.* The glass rod is called the inducing body, its charge the "inducing electricity," while either of the electricities produced by the action of the inducing body is called "induced electricity." The action, however, differs essentially from that of a magnet in one respect. By electric induction we may cause a complete separation of the two kinds of electricity, so that one body is all positive and the other all negative; on the other hand, when a magnet induces north and south magnetism, these two are inseparable and both are always found together in the same bar of iron or steel, one kind of magnetism seeming incapable of existing in a body without the other.

QUESTIONS ON CHAPTER XXV

1. By what experiments would you prove that a glass rod after being rubbed with silk is in a different state from one which has not been rubbed?

2. By what experiments would you prove that a rubbed glass rod is in a different state from a rubbed stick of sealing-wax?

3. Describe fully the experiments which prove that there are two electrical states.

4. Supposing that some paper has been rubbed with india-rubber, some china with silk, and some ebonite with a cat's fur, how would you arrange a set of experiments to show the kind of electricity produced in the paper, china, and ebonite? Try the experiments.

5. Explain why it is that an electrified body first attracts and then repels light bodies.

6. Explain why you cannot electrify a metal rod by holding it in your hand and rubbing it with cat's fur. How would you arrange matters so as to be able to electrify it? Try the experiment.

7. Explain what is meant by a *conductor* and what by an *insulator*. Devise some experiments which show that water is a good conductor of electricity, and try them.

8. Give a careful account of the experiments on electric induction performed in the last chapter, and explain how it is proved that the induced electricity nearer to the inducing body is of the opposite kind, and that more distant of the same kind as that of the inducing body.

9. State in what respects magnetic induction resembles electric induction, and in what respects the two differ.

APPENDIX A

HINTS FOR PERFORMING THE EXPERIMENTS

Chapter I

Experiment 1.—Stiff brown paper, about one foot square, is best. The motion should be a kind of sweeping, so that the outer edge of the paper passes close to the outstretched left hand.

Experiment 4.—An india-rubber stopper, with a central hole, which is a little smaller than the width of the tube of the funnel, should be used. Insert the stopper into the neck of the bottle first, then pass the funnel tube through the central hole with a twisting motion, grasping the edge of the funnel with the outspread fingers of the right hand over the opening, and holding the neck of the bottle with the left. Instead of the stopper a cork may be employed. It must be slightly wider than the mouth of the bottle, and should be gently hammered, so as to soften it, and then the central hole made with a cork-borer of suitable size.

Chapter II

Experiment 1.—The glass plates should not be much larger than the mouth of the tumblers. Two *beakers* of the same size, with round glass plates, are best. Water is poured into one until quite full, and the glass plate put upon it, so that no air is left between it and the water. Any water which has run over should be carefully wiped off all round.

Experiment 3.—A glass plate such as is used for photographic pictures, about six inches square, is best. A somewhat

large trough of Doulton ware, about fifteen or eighteen inches in diameter, and six or eight inches deep, is desirable for this and several other experiments.

Chapter III

Experiment 3.—The glass tube should be about one foot long, and an inch and a half or more wide. An ordinary lamp-chimney is well adapted for the experiment. It is placed upright on a piece of stiff paper, a pencil mark drawn round it, and the disk cut out with the scissors. A fine string, about a foot and a half long, is drawn with a needle through the centre and fixed by a knot, and the hole closed with sealing-wax.

Experiment 4.—To recognise the difference of levels better, the water poured into the interior of the tube should be coloured; this may be done with a few drops of ink or sulphate of indigo.

Experiment 5.—Glass tubes are best bent by heating them by a so-called fish-tail burner. The part to be bent is held along the upper part of flame, and the tube constantly turned round and round; when quite soft it is removed from the flame, still keeping it straight with both hands, and then bent to the required form with a single motion. Bends near the end of a tube are best made by forming a bend with a longer bit, and cutting off the portion not wanted. This is done by making a scratch with a sharp triangular file, and then pulling the parts asunder, placing the thumbs on the side opposite to the scratch and underneath it.

Chapter IV

Experiment 2.—To close a tube heat it about two or three inches from the end *across* the flame of a fish-tail burner, turning the tube constantly until it is soft. Remove it from the flame and pull out the softened portion gently, but not so as quite to separate the two sides, and hold the tube steadily in a straight line until it is hard again. Wipe off any soot that is left with a piece of cloth. Now heat that part of the contracted portion which is towards the side of the tube which is to be used, until

it is soft; again pull steadily, keeping the whole in a line, and wait until it has hardened. Repeat the heating, pulling, and waiting until nothing but a thread of glass remains to connect the two portions. This thread is now heated where it joins the tube until it fuses, and the parts are then separated. The small knob left at the closed end may be rounded off by directing an ordinary blowpipe flame upon it until it fuses and incorporates itself with the surrounding glass.

Chapter V

Experiment 2.—Care is required in handling mercury, for it is difficult to recover when spilt, and its vapour is poisonous. It is therefore advisable to place the dish used in this experiment upon a tray which has a rim all round, or at least upon the bottom of a deep soup-plate, both while the mercury is poured into it from the bottle in which it is kept, and during the experiment. When the mercury is to be poured back, use a wide funnel, if possible wider than the dish used.

Chapter VI

Experiment 1.—The salt, sugar (white loaf sugar), and sand should each be in the state of a fine powder. The salt and sugar may be ground in a mortar; the ordinary *silver sand* is fine enough. The pinches taken should be carefully adjusted, so as to be alike in quantity, both in this experiment and in experiment 4.

Experiment 3.—Filter papers are sold cut into circles of different sizes. A piece is folded in the middle, so as to form a semicircle, that is, half a circle; this is again folded at right angles to the first fold, and the circle is thus reduced to a quadrant, that is, a quarter of a circle, consisting of four thicknesses of paper. Open this out, so as to form a tapering cavity, having three folds of the paper on one side and one on the other. The funnel in which it is placed should be a little larger than the filter. Care must be taken in handling the filter-paper not to injure the point, which bears most pressure, though it is the weakest part, on account of the four creases which meet there.

Chapter VII

Experiment 1.—It is important to add equal quantities each time, both in this and in the other experiments, where the solubility is a subject of comparison. The employment of a very small bone spoon, or a bit of stiff paper, will with careful adjustment of the small quantities taken each time render the comparison as good as if a balance were used.

Flasks, dishes, etc., in which liquids are heated, are very conveniently supported by a tripod, which consists of a stout ring of iron or brass, fixed upon three legs.

Experiment 3.—Whenever a liquid which contains solids in solution is to be evaporated it should be done without excess of heat, so as to prevent spurting and consequent loss. The top of the flame should just reach the bottom of the vessel in which the liquid is contained.

Experiment 5.—It is best to take out a drop of the solution now and then with the end of a glass rod, and thus to observe the gradual change more closely than can be done by merely looking into the dish. Touch the drop when cold with the finger, and observe its gradual hardening.

Chapter VIII

Experiment 1.—It is best to place a dish beneath the mouth of the test-tube to prevent the tarry liquid from dropping on the table.

Experiment 2.—The short tube with a narrow pointed opening is easily made by heating a bit of tubing in the middle, and pulling it out when soft, but without quite separating into two parts. The tube is separated by a gentle scratch of the file at the point where it has become thinnest.

Experiment 5.—The copper and iron must be quite bright before heating them. A small flat piece of copper (foil) and a bright knife-blade are very suitable. The copper may be fixed into a piece of cork while holding it in the flame.

Chapter IX

Experiment 1.—Place a piece of iron wire-gauze on the tripod, and the bottle upon that, so that it may not crack. It is advisable to employ a sponge or cloth to wipe the water off now and then.

Experiment 2.—The tube should project into the bottle an inch or two below the stopper, otherwise air, which has been dissolved in the water, will collect at the top, and shut off the connection between tube and liquid. It is advisable to colour the water with a little indigo-solution.

Experiment 3.—A strip of cardboard narrower than the beaker is placed across its mouth after making two holes side by side in the cardboard, into which the test-tubes fit tightly. The two liquids may conveniently just reach up to the cardboard, and the hot water is poured on so that its surface is a small distance below it.

Experiment 4.—The bottle with the tube used in Experiment 1 may be used for this instead of the tube with the bulb. It must, however, be carefully dried inside before making this experiment with it. The bulb is heated by gently moving a spirit flame to and fro about it for a short time. If it is heated too long the liquid will afterwards rise into the bulb and may crack it. The liquid should not rise higher, when the bulb is quite cold, than about half-way up the tube, or the apparatus is not adapted for the next experiments.

Chapter X

Experiment 1.—A cylindrical jar, about two or three inches wide and from one to two feet high, is best, but any ordinary wide-mouthed glass jar will do for the experiment. After washing it out with water, some filings are thrown in, the jar is moved about so that some of the iron adheres all round, and the remainder is allowed to fall out again. Have the plate or saucer with water ready, and immediately invert the jar over it. The rise of the water will be seen in a short time.

Experiment 3.—A small test-tube is made by heating a piece of glass-tubing, about six inches long, in the middle across the fan-tail burner, and quickly drawing apart when soft. We shall then have two test-tubes, each having a thread of glass at the end, which may be fused into the end by heating again and turning the tube round and round.

CHAPTER XI

Experiment 1.—The taper for the narrow-necked bottle may be stuck upon the end of a long wire which is slightly bent upwards.

Experiment 2.—The tubes should be about three-quarters of an inch in diameter, and fit tightly in the holes. They may be either of glass or metal.

Experiment 3.—The bell-jar should be pressed firmly against the bottom of the plate which contains the water, or some gas will escape.

CHAPTER XII

Experiment 1.—Any acid will do instead of vinegar. The bottle should be somewhat deep, and if the candle is not put out immediately, it should be withdrawn and a little more acid added.

Experiment 3.—The chalk must be the crude mineral, not the kind of chalk used for writing, which is specially prepared, and useless for experiments.

Experiment 5.—It is desirable to fill the bottle up to the stopper with the limewater, or it will soon be rendered useless by the action of the air left in it. The stopper should fit very tightly.

CHAPTER XIII

Experiment 4.—The liquids should not be boiled, but gently heated over two spirit lamps near each other, and the discharge of bubbles compared.

Chapter XVI

Experiment 1.—A piece of lead gas-piping, a quarter of an inch bore, and about two inches long, is hammered at one end, till it is well closed. The sodium is rammed quickly into the open end with a piece of stout iron wire, or a glass rod.

Experiment 4.—The tube T should be fixed in an inclined position as shown in the figure, so that any water which is condensed may flow back into the flask and not break the tube. A piece of hard glass-tubing of the kind called "combustion tubing" is required.

Chapter XVII

Experiment 3.—The water required is best prepared by mixing a bottleful of soda water with an equal quantity of ordinary water. If more is required to fill the jar, mix in the same proportion.

Chapter XVIII

Experiment 4.—When experimenting with clay it is necessary to crush the dry clay in a mortar, and after first adding a very little water, to rub it with the pestle to a stiff but uniform paste. Then more water is gradually added, the mass being continuously worked round with the pestle until it is easily kneaded by the hands.

Chapter XIX

Experiments 3 and 4.—The thermometer should be used to stir the liquids, to which the hot water and the ice have been respectively added, before making an observation.

Experiment 5.—Into one beaker 1 lb. of water, and into the other 2 lbs. may be poured, each roughly measured out from a suitable measure, and the times which are required for bringing the water to the boiling-point in the two cases compared.

Place both vessels upon a piece of tinned iron upon a tripod, a little way apart, and arrange the burner underneath so as to be just in the middle between them.

Chapter XX

Experiment 1.—Ordinary test-tubes are too thin for melting solids; they crack too easily, and may melt themselves before the solid fuses. Small tubes suitable for this purpose are made from a piece of ordinary soft glass-tubing, a little wider than that used for making gases, with the help of the blowpipe. A piece of about five or six inches in length is softened in the middle by holding it across the flame of a fish-tail burner (an ordinary gas-flame as is used in rooms for lighting); when soft it is quickly drawn out to form two tubes connected by a mere thread of glass, which is then detached from each tube by directing the flame with the blowpipe across the tail near the point where it is attached to the wider portion of the tube. When cold the soot is wiped off with a cloth.

Experiment 4.—The more intimate the mixture, that is, the more finely the ice has been pounded before mixing it with the salt, the greater is the fall of temperature. The best mixture is 3 lbs. of finely-crushed ice with 1 lb. of salt.

Experiment 7.—The vessel may be made out of an ordinary test-tube of small size, which is drawn out to a point over a gas-flame. The tube may be much more easily handled during this operation, and may be drawn out very near the mouth without burning the fingers if a cork fitting moderately tightly is pushed about a quarter of an inch into the tube, so as to serve as a handle for turning it while it is heated. A small groove must be formed lengthways in the cork by two slanting cuts with a sharp knife, so as to allow the air to expand when the tube is heated, otherwise the confined air would blow out the glass as soon as it became soft by the heat. The point is carefully broken off, water poured in by means of a funnel with a fine point, so as nearly to reach the top, and then the aperture again closed with the blowpipe.

Chapter XXI

Experiment 4. — The tube leading the steam into the cylinder should be bent slightly upwards as shown in Fig. 18,

so that a portion of the condensed water may flow back into the flask. It is well to use a graduated cylinder, so as to deal with exactly equal quantities in Experiments 3 and 4. Strips of paper may be pasted outside as marks if no suitable graduated vessel is at our disposal. The *added* hot water and steam should be about one-fifteenth of the whole in either case.

Chapter XXII

Experiments 4 and 6 may not succeed satisfactorily at first, and may require repetition. In Experiment 6 the tube should be turned and the hot end made the free one if difficulty is experienced. It is advisable to construct a little wire-holder for it, so that the fingers may not be burnt, and so that it may be held at a moderately small angle with the axis of the flame.

Chapter XXIII

Experiments 1, 2, 3.—The best test-tubes for these experiments are made out of ordinary glass-tubing about a quarter of an inch in diameter. A piece about ten or twelve inches in length is cut off and heated in the middle over a fish-tail burner, as for Experiment 1, Chapter XX.

APPENDIX B

LIST OF MATERIALS, ETC., REQUIRED FOR THE EXPERIMENTS OF EACH CHAPTER.

CHAP.

I. Some sheets of stout paper. A wide vessel with water (Fig. 1). A glass tumbler. A glass bottle. A perforated stopper. A funnel with narrow tube (Fig. 2). A long very narrow glass tube.

II. Two tumblers of similar shape. Several glass plates. A pail of water. An oily rag.

III. A tumbler. A wide jar with water. A vessel of glass or tin with a small hole in its bottom (Fig. 3). A piece of wide glass-tubing. Some string, cardboard or leather, and mercury. A tall glass jar with water, and two tubes bent as *a* and *b* in Fig. 5.

IV. A tumbler. Some stiff paper. A pair of scissors. A long very narrow glass tube, closed at one end. A bottle or jar of glass. A dish of water (Fig. 6). A tube bent as Fig. 7. Some india-rubber tubing.

V. A sheet of paper. A dish full of water. A plate of glass. Some glass-tubing, sealing-wax, bright lead, and mercury in a small dish. A quantity of salt. An egg. Several tumblers. Water. Glass rod or spoon.

VI. Three or more tumblers of equal size, and several others. Some water, salt, sugar, and sand. Glass rod or spoon. A shallow dish. A funnel with stand. Filter-paper.

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VII. A tripod stand and wire-gauze. Several beakers. Some salt and sugar. Several china dishes. A tumbler.

VIII. A spirit lamp. Scraps of wood. Test-tubes. Perforated stopper with short glass tube, having a pointed end (Fig. 8). Some sugar. A china dish. Some tin. A bright piece of iron, and of copper.

IX. A glass flask. Tripod. A gas-burner or spirit lamp. Glass tube (Fig. 9). Stopper. Test-tubes. Alcohol. A beaker. Glass tube with bulb (Fig. 10). A piece of cloth. A little benzene and ether.

X. A tall glass jar. Some iron filings. A dish with some water. A plate of glass. A taper. A small test-tube. A little red oxide of mercury.

XI. Two bottles or jars, one wide-mouthed, the other with a narrow neck. A piece of candle. Cork with two holes. Tubes (Fig. 11). A piece of cork. A bell-jar. A flat dish.

XII. Some bits of marble, chalk, or limestone. A bottle. Some vinegar or other acid. A blowpipe. Charcoal. Some quicklime. A tin plate. Some water. A little gypsum.

XIII. Apparatus Fig. 12. Jars. A candle. Some small beakers. Apparatus Fig. 13.

XIV. A tumbler. Some water. Limewater. Tripod, glass flask, and burner. Apparatus Fig. 12. A beaker.

XV. A small glass plate, or a watch-glass. Some salt. Test-tubes. Some magenta, or some solution of indigo. Apparatus for distillation (Fig. 14).

XVI. A piece of sodium. Some lead-tubing. A short piece of stout wire. A dish with water. A wide test-tube, or small jar. A long taper. A knife. Iron filings. Apparatus Fig. 15. Test-tubes. Some zinc. A little sulphuric acid. A little copper-foil. Apparatus Fig. 16.

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XVII. A bottle with a narrow neck (Fig. 17). Long wire with taper. A candle. A beaker. Fresh leaves. Some soda water. Large jar and dish with water.

XVIII. Two similar glass vessels. A little water and a little mercury. Tubes of various diameters. Some blotting-paper, sugar, cotton wick, and a bit of sponge. A clean board. A little oil. Some clay. A gas burner. Some alcohol and some turpentine.

XIX. An ordinary thermometer. Two vessels with water. Some hot water. Some snow, or broken ice. Two similar beakers.

XX. Some salt. A small test-tube. Two beakers containing water. A thermometer. Some ammonium nitrate. Some snow, or pounded ice. Test-tubes, one rather wide. Some sodium hyposulphite. A beaker with boiling water. A piece of stearine candle without wick. A closed glass vessel made from a test-tube.

XXI. Some alcohol, oil, water, and ether. A cylindrical glass vessel (Fig. 18), flask, and tube. A thermometer. A little muslin. Apparatus for distillation. Some rose leaves, or petals of pinks, fresh peels of lemons, fennel seeds, caraway seeds.

XXII. A few sticks of caustic potash. Beakers. Thermometer. A small dish. Some sulphuric acid. A piece of writing paper. Some water. A gas burner. Some wire-gauze. A short piece of glass-tubing. A candle. A china dish.

XXIII. A long narrow test-tube. A burner or spirit lamp. Some mercury. Some thin iron and copper wire. A foot-rule. A short piece of thick iron wire.

XXIV. Some steel knitting-needles. Fine thread. Two stands with horizontal arms. Thin glass-tubing. Lead pencils. Pieces of stout wire of copper or brass. Several straight magnets, one very small, some of

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ordinary size, and one as large as possible. A file. Some iron filings.

XXV. A paper stirrup. A wooden stick. Several stout glass rods. Some whole sticks of sealing-wax. Dry warmed pieces of silk and of flannel. Some sticks of sulphur, or rods of ebonite. Small bits of paper. Electrical pendulums with glass and metal supports, and silk and cotton suspension. Two coins fixed on pieces of sealing-wax. A very small wooden board.

THE END

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